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SUBJECTIVE IMAGE QUALITY COMPARISONS OF AMLCD AND CRT IMPLEMENTATIONS OF ELECTRONIC FLIGHT FORMATS

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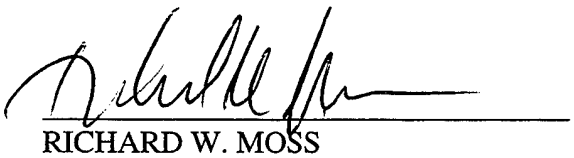

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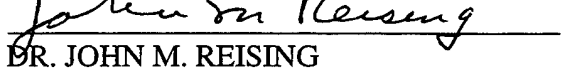

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13. ABSTRACT *(Maximum 200 words)*

This report discusses the methods and results of a study which compared the useability of proposed electronic flight formats presented on a Cathode Ray Tube (CRT) to the same formats presented on an Active Matrix Liquid Crystal Display (AMLCD). Eight subject pilots performed a series of flying tasks in two simulator sessions: one with a commercial grade CRT and the other with a commercial grade, prototype AMLCD. Subjective assessments were obtained via questionnaires that addressed image quality and useability issues. The results showed that the display formats that were developed and tested on a CRT could be implemented on the test AMLCD hardware with no significant degradation in image quality or useability. Some considerations for optimizing formats for AMLCD implementations are discussed.

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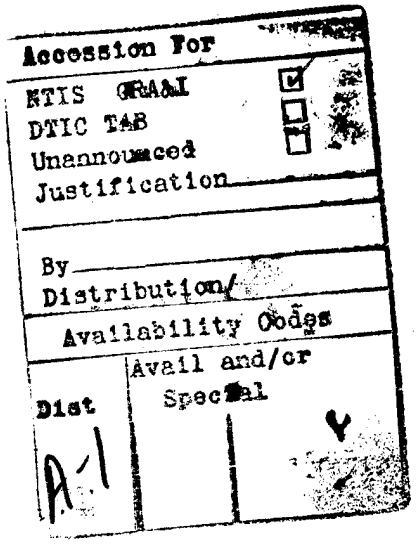

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INTRODUCTION

As Active-Matrix Liquid Crystal Display (AMLCD) technology has matured, it has been increasingly used as an alternative to Cathode Ray Tubes (CRTs). In fact, image quality of AMLCDs rivals that of high resolution CRTs. CRTs, however, are often being used for prototyping AMLCD applications because of their greater flexibility, wider availability and relatively lower cost. This raises issues concerning the image quality differences that may exist between the two display types. Because AMLCDs and CRTs have different imaging characteristics, the appearance of identical formats, and potentially their usability, can be affected.

The issues involved with implementing formats, that were developed and tested on a CRT, onto an AMLCD was of particular interest to Wright Laboratory in their support of the C-141 upgrade program. This effort, which is being accomplished by Warner Robins (WR/ALC), involves replacing C-141 electromechanical flight instruments with four AMLCD units, two at each pilot's position. Wright Laboratory supported this effort through the evaluation of proposed electronic flight formats in a two phase simulation effort. The first phase consisted of a part-task evaluation (Cone, Toms, Gier, Brown, and Patzek, 1995) and the second phase consisted of a full mission evaluation (Toms, Cone, Gier, Boucek, Brown, and Patzek, 1995). CRTs (commercial grade), rather than AMLCDs, were used for format development and the two evaluations.

Wright Laboratory has since acquired AMLCD hardware and has conducted a program to determine if previous simulation findings, based on the tested CRT, were valid for an AMLCD. The objectives of this effort were: 1) to evaluate *image quality and integrity* issues associated with transferring the Primary Flight Display (PFD) and Secondary Flight Display (SFD) formats from a CRT to an AMLCD; and 2) to determine if potential image quality differences will affect the *useability* of these formats and prevent their transition to the AMLCD hardware. The PFD and SFD formats are depicted in Figure 1. The scope of this effort was limited by the specific imaging characteristics of the test AMLCD, which was not designed to military specifications for use in the cockpit. However, the results of this study will point to potential areas of concern relevant to implementing the proposed flight formats on an AMLCD.

General Approach

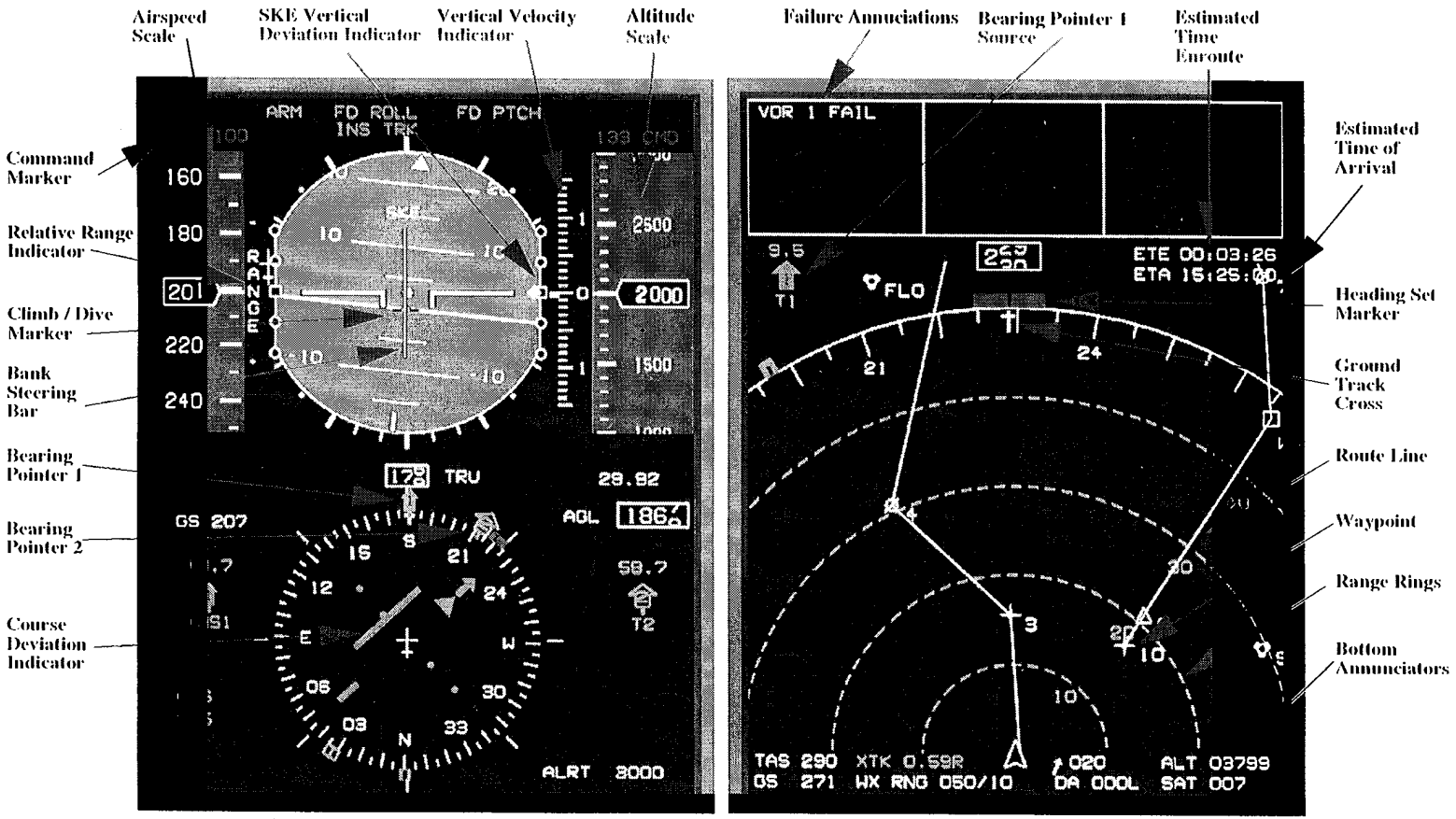
To accomplish the test objectives, pilots subjectively evaluated and compared AMLCD and CRT implementations of the proposed C-141 display formats in two simulator flying sessions. The same CRT that was used in the previous evaluations (i.e., part-task and full mission simulations) was used in this study.

Subjective image quality assessments were collected via questionnaires administered during and after the test sessions. The purpose of the questionnaires was to assess *image quality* and *useability* issues associated with the test AMLCD and CRT. Specifically, the questionnaires addressed: 1) observed image anomalies on the displays, 2) image quality differences between the two display types on a variety of dimensions and 3) display format useability and subjective task performance.

During the test sessions, pilots flew three tasks: formation flying, precision instrument maneuvers, and navigation/approach. These were selected because they were representative of military transport operational tasks and they fully exercised display symbology in a variety of dynamic conditions. Flying with the formats allowed subjects to interact with display elements and to assess any usability concerns. Subjects were also given a period of time during each task to observe the display symbology, without flying, so that they could focus on the dynamics of the PFD and SFD symbology and on any image anomalies that may be present.

LCD/AMLCD Image Quality Characteristics

To assist in the development of the evaluation methodology, a literature review of LCD/AMLCD image quality characteristics was accomplished. Although AMLCDs provide an acceptable image quality, the review revealed that they can be affected by troublesome anomalies which may



Primary Flight Display

Secondary Flight Display (Map)

Figure 1. Proposed C-141 PFD and SFD Map Formats

degrade viewing. Those that are relevant to the current study are briefly described in the following three major categories: chromatic characteristics, motion/ spatial artifacts, and luminance anomalies.

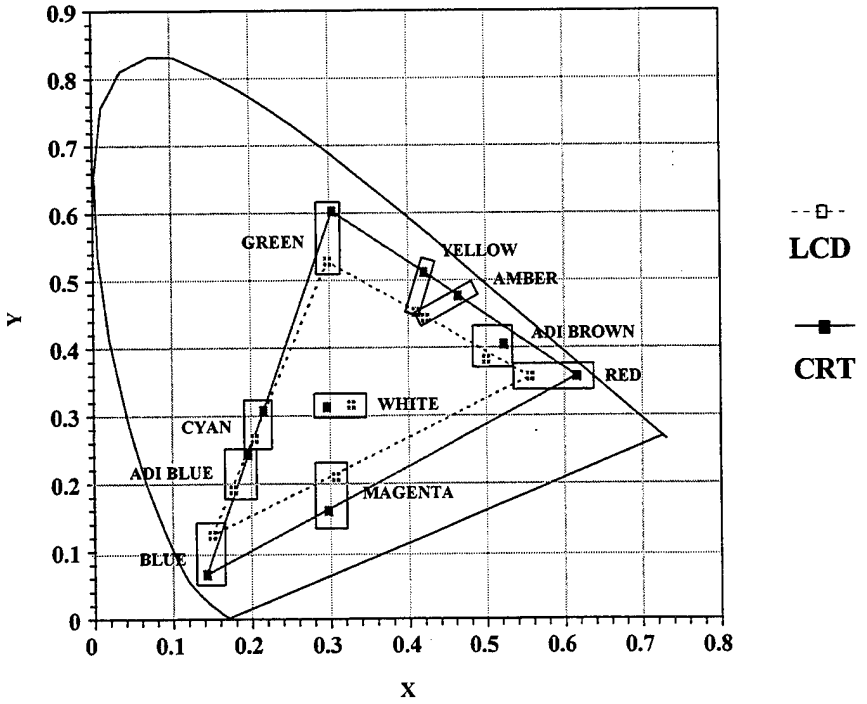
Chromatic Characteristics

In dark ambient conditions, an LCD color gamut is often located within a CRT color gamut (Figure 2). Some LCD colors are, therefore, less saturated than the CRT colors. Also, fewer discriminable colors can be produced by the LCD in these conditions. In bright ambient conditions (e.g., 8,000 foot candles), the opposite is generally true. That is, the LCD color gamut is typically located outside the CRT gamut (Jacobsen, 1988). Consequently, an LCD can produce more saturated and discriminable colors than the CRT under bright ambient conditions, thus making the multi-color LCD more "sunlight readable" than the CRT.

Several color artifacts can occur on LCDs (Krantz, J.H., 1992; Hopper, D.G. & Dolezal, W.K, 1994). The most critical of these is the shift in colors that occurs as a function of viewing angle. Other artifacts include "color banding" and "color fringing." Color banding appears as a non-uniform distribution of color within a line or symbol. Color fringing appears as color distortion along the symbol's edge, and occurs as a result of an interaction of a line orientation with "pixel pattern geometry" (Hopper, D.H. & Dolezal, W.K., 1994).

Motion / Spatial Artifacts

The discrete nature of LCD pixels results in a very sharp and clear display. However, this sharp pixel definition can also result in the appearance of motion and spatial artifacts which may be less noticeable on a CRT. Lines or symbols can be disfigured or have a jagged, stair-stepping appearance. Research has shown that these effects can be exaggerated when multiple symbols interact, as occurs when symbol layering or masking techniques are employed (Weidenmann, J. and Trujillo, E.J., 1993). Symbols that rotate over a spatial pattern can sometimes take on a "swimming" appearance. When in motion, symbols may also exhibit jitter or ratcheting effects.



1931 CIE CHROMATICITY DIAGRAM

Figure 2. Test AMLCD and CRT Color Gamuts

Antialiasing techniques can minimize many of these anomalies.

Luminance Anomalies

A variety of luminance anomalies can occur with LCDs. As with color, the most critical anomaly is the change in luminance and contrast as a function of viewing angle. Other luminance anomalies may be spatial or temporal in nature and may occur across various areas of the display. A common spatial luminance anomaly is a "3-dimensional corrugated effect" that can appear either across the display or that may appear across the entire surface or a large fill area of a display. This effect can be attributed to the modulation of the florescent backlighting that is often used on LCDs. Another spatial luminance anomaly is "roping" which is defined as a periodic luminance modulation along a line producing a rope-like appearance (Hopper, D.H. & Dolezal, W.K., 1994). Flicker, an undesired rapid temporal variation in luminance, is an example of a temporal anomaly.

Summary

A review of the literature has indicated that several anomalies can affect image quality on the LCD. These anomalies include: color shifting with off-axis viewing, the appearance of image artifacts with symbol movement, and luminance distortions. The potential presence of these image anomalies on the test AMLCD guided our test methodology.

METHOD

Subjects

Eight pilots participated in the evaluation. Their experience level varied from copilot to instructor pilot, with an average of 3136 hours of flying experience. Five of the eight pilots were active C-141 pilots with an average flying time of 3060 hours. Other aircraft experience included: A-7, F-111, F-117, KC-135 and Boeing 727.

Apparatus

Transport Aircraft Cockpit (TRAC) Simulator

The evaluation was conducted in the Transport Aircraft Cockpit (TRAC) simulator located in the Wright Laboratory Crew Systems Integration Laboratory (CSIL). The simulator was configured to approximate a C-141 cockpit geometry and consisted of two crew stations: pilot and copilot. A C-141 aeromodel was used to drive the simulator and an electric torque motor control loading system was used to provide a realistic flight control feel.

Both the pilot and copilot stations were configured for flying tasks. The pilot's station was configured with an AMLCD and the copilot's station was configured with a CRT monitor. Both the AMLCD and CRT were driven by Silicon Graphics computer systems. Antialiasing was provided by the Silicon Graphics systems to both displays. Figure 3 shows a picture of the TRAC simulator configured with the formats used in the study.

Display Formats

The Primary and Secondary Flight Display (PFD / SFD) formats that were proposed for the C-141 cockpit upgrade effort were used in the evaluation. Figure 1 illustrates the proposed PFD and SFD Map formats that were used in the study. The PFD graphically displayed primary flight instruments including: an Attitude Director Indicator (ADI), a Horizontal Situation Indicator (HSI), an Airspeed Indicator, a Barometric Altitude Indicator, and a Vertical Velocity Indicator (VVI). The SFD graphically displayed one of three pages: Map (on INS route overlaid on a radar map), HSI (an expanded HSI), or Station Keeping Equipment - SKE (a display repeat of the SKE scope). A complete discussion of the formats can be found in the C-141 full mission simulation report (Toms, Cone *et al.*, 1995).

Test Display Hardware

The CRT used for testing was a Mitsubishi 21 inch diagonal monitor (Model #FHL6115 STK) designed for commercial applications. This same monitor was used for the C-141 format development and evaluation effort. The CRT had a vertical pixel density of 92 pixels per inch and a horizontal pixel density of 86 pixels per inch. A 6 x 8 inch area on the right half of the display monitor was used for presenting either the PFD or SFD display formats. A touch screen overlay covered the display viewing area, but was not active for the current study.

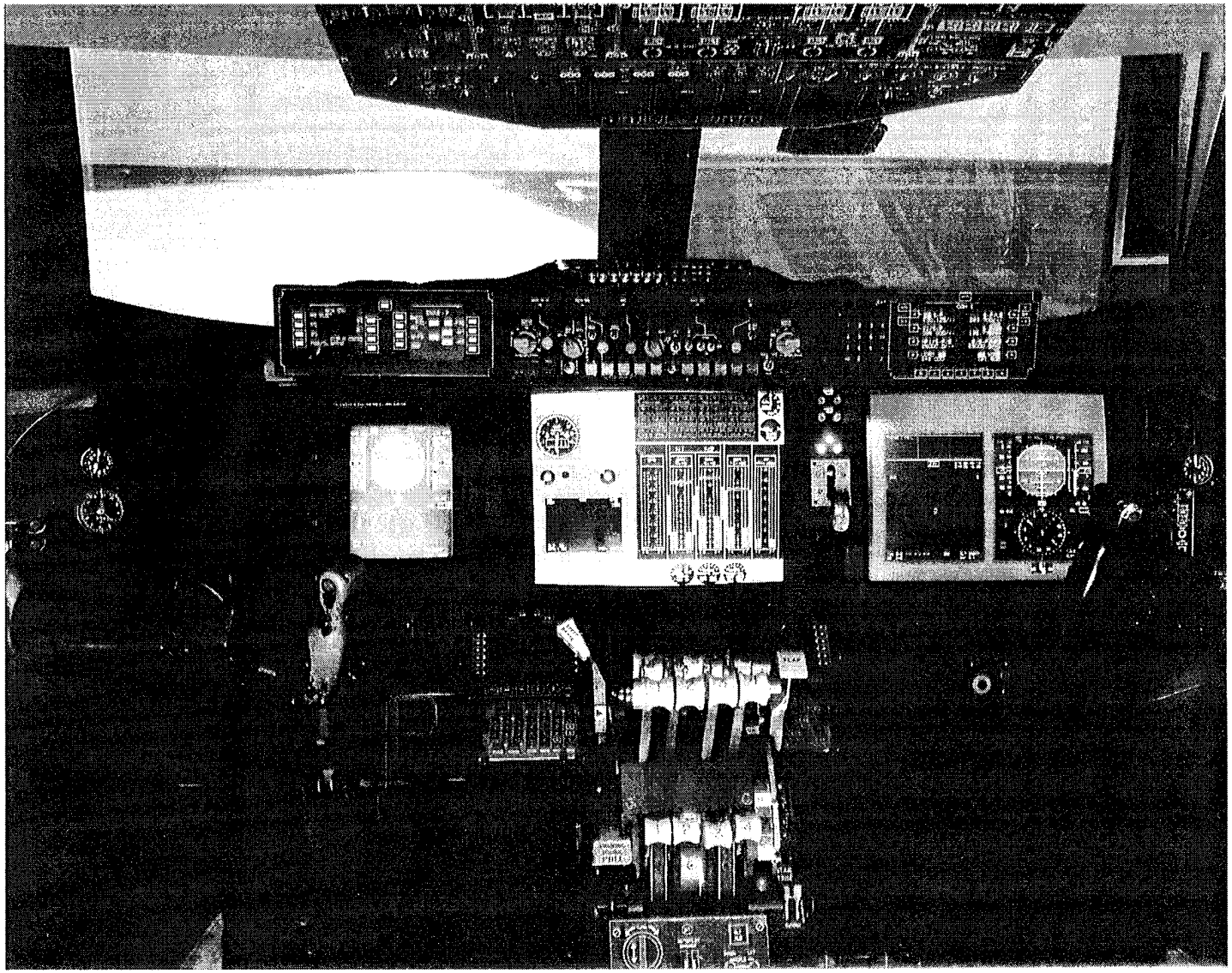


Figure 3. TRAC Simulator

The AMLCD used in the study was a prototype Interstate 6 x 8 inch color AMLCD with a VGA interface and was intended for commercial applications. This display was originally designed to be shown in a landscape mode. However, to accommodate the cockpit application and testing requirements, the AMLCD was rotated 90° for portrait mode presentation. This rotation resulted in a lateral viewing angle of +/- 20 degrees and a vertical viewing angle of +/- 40 degrees. Because of this unusual off-axis viewability limitation, cross-cockpit viewing was not evaluated in the current study. In the portrait mode, this AMLCD had a vertical and horizontal pixel density of 77 pixels per inch. This resulted in a resolution of 5929 pixels per square inch, compared to the CRT's resolution of 7912 pixels per square inch.

The colors for the test AMLCD could not be exactly matched to the test CRT because its color gamut was smaller than the CRT's color gamut. Rather, the AMLCD hues were adjusted to match as closely as possible to the CRT hues, and the most saturated versions of the AMLCD hues were used for testing. Figure 2 shows the AMLCD and CRT chromaticity coordinates for the display colors used in the study.

The luminance setting for the AMLCD was matched as closely as possible to the CRT luminance setting for white. These settings were 4.45 fL for the CRT, which was used in prior C-141 development studies, and 4.65 fL for the AMLCD.

Procedure

Each subject participated in one-half day of training and one-half day of testing.

Training

Training was approximately three hours and consisted of two sessions: 1.5 hours of ground training and 1.5 hours of simulator flight training. This schedule allowed the pilot to develop sufficient proficiency in simulator control and display interpretation to permit a valid analysis of the AMLCD.

Ground training consisted of an overview of administrative items, evaluation procedures, image quality terminology, and cockpit familiarization. Cockpit familiarization was limited to the symbology of the C-141 formats, their mechanizations and use of the various controls. The simulator flight training consisted of the subject pilot flying a subset of the evaluation tasks which encompassed: flying SKE formation, performing a vertical "S"- D and a steep bank turn, and flying an Instrument Landing System (ILS) approach in Instrument Meteorological Conditions (IMC).

Testing

Testing was conducted in the TRAC simulator and consisted of two data collection sessions. Each session was approximately 1.5 hours. One session consisted of displaying proposed C-141 formats on the CRT and the other session consisted of displaying the same formats on the AMLCD. Display order (i.e., CRT or AMLCD) was counterbalanced to compensate for carry-over effects. The simulation testing sessions were conducted in dark ambient conditions. All simulator sessions were video taped recorded.

The flight profile was the same for both testing sessions and consisted of three tasks: 1) Formation Flight, 2) Precision Instrument Maneuvers and 3) Navigation/Approach. The flight profile is depicted in Figure 4. All tasks were flown with a subject pilot and an experimenter copilot. For each task, the subject flew for approximately 20 minutes, and then the experimenter copilot took control of the aircraft and flew similar tasks. The time that the experimenter copilot flew (observation period) gave the subject pilot the opportunity to observe and focus on the dynamics of the PFD symbology. This period also allowed the SFD pages to be evaluated since only one format, either the PFD or SFD, could be displayed on the AMLCD at any given time. The SFD SKE page was shown with the Formation Flight task, the SFD Map page was shown with the Precision Instrument Maneuvers task and the expanded HSI page was shown with the Navigation/Approach task.

Before the start of each task, subjects were briefed on the flight parameters. They were also given the opportunity to set cockpit controls, and established the airspeed, altitude and heading required to perform the task. Since performance data were not collected, subject pilots were instructed to place their emphasis on observing the display symbology and various symbol element interactions, rather than on flying performance. Subjects were also

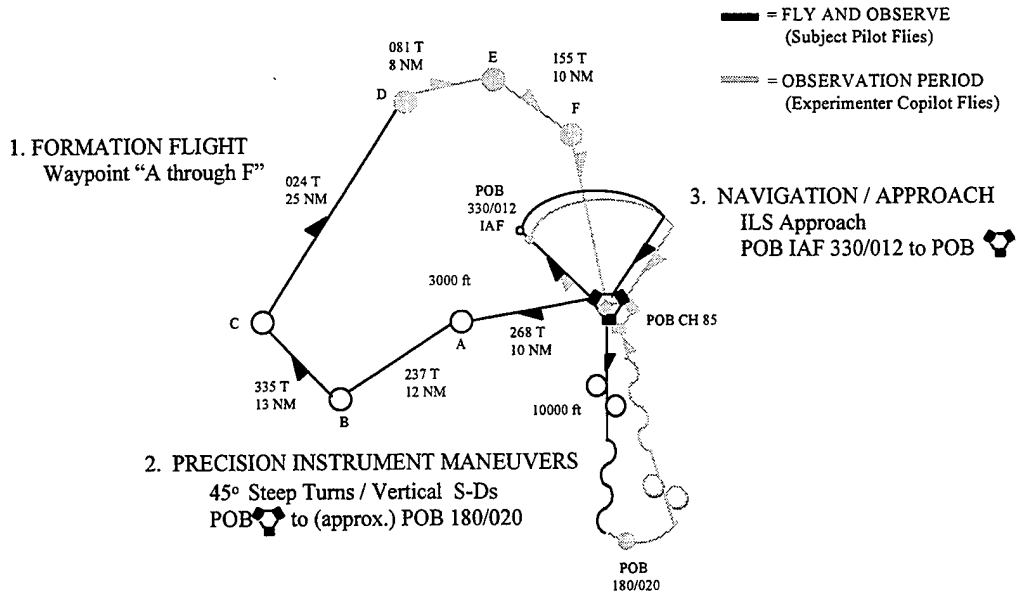


Figure 4. Flight Profile

given the opportunity to revisit any task for additional observation of the dynamics of the PFD or SFD display symbologies. The following is a brief description of each task segment of the flight profile depicted in Figure 4.

Formation Flight

The first task consisted of formation flying using SKE procedures. The subject aircraft was the #2 position of a three ship formation. The task began with takeoff behind lead. The climbout was a right turn to intercept a 268° True Track to the low level route entry point (point "A" on the Flight Profile). The formation then climbed unrestricted to 3,000 feet and accelerated to 240 Knots Indicated Airspeed (KIAS). The subject pilot flew the SKE route (maintaining position) through point "D". After point "D," the copilot took control of the aircraft and continued the SKE route. This allowed the pilot to focus on the display symbology and SKE elements of the PFD and SFD formats. Upon reaching the Pope VORTAC (POB), the subject pilot regained control of the aircraft, broke formation, climbed to 10,000 feet, and slowed to 180 KIAS in preparation for the Precision Instrument Maneuvers task.

The purpose of the formation flight task was to demonstrate the dynamic movements of the SKE symbology with other ADI display symbology on the PFD. Pilots were able to assess the distinctiveness of the SKE symbology against adjacent symbology, a potential area of concern revealed in the full mission evaluation (Toms, Cone *et al.*, 1995). Also the pilot was able to observe and evaluate formation symbology on the SKE page of the SFD.

Precision Instrument Maneuvers

The second task consisted of two instrument maneuvers flown according to procedures defined in AFM 51-37. The first maneuver consisted of two 45° steep bank turns. The second consisted two vertical "S"-D maneuvers, in which the pilot maintained a constant bank and descent (or climb) and reversed direction of turn when vertical direction changed (i.e, changed from descent to climb or vice versa).

Both maneuvers began once the subject pilot stabilized the aircraft at 10,000 feet and 180 KIAS. The pilot was instructed to maintain 180 KIAS throughout the maneuvers. With the steep bank

turns, the pilot first made a constant speed 45° bank-level, 360° turn in one direction and then made a second 360° turn in the opposite direction. For the vertical "S"-Ds, the pilot executed a left 30° bank descending turn at 1,000 ft/min; and then, upon approaching 9,000 feet, transitioned to a right 30° bank climbing turn at 1,000 ft/min. The transition from a descending turn to a climbing turn was to be accomplished so that the aircraft passed through 9,000 feet, wings level on the horizon line. The vertical "S"-D was repeated once the aircraft was stabilized at 10,000 feet and 180 KIAS.

Upon completion of both maneuvers (i.e., steep bank turns and vertical "S"-Ds), the experimenter copilot took control of the aircraft and repeated the same maneuvers. The experimenter copilot then descended the aircraft to 3,000 feet and accelerated to 250 KIAS, reversed direction of flight, and proceeded direct to Pope VOR in preparation for the Navigation/Approach task.

The steep bank turn and vertical "S"-D maneuvers were determined as being best suited for demonstrating "extreme" dynamic movements of the ADI and HSI symbol elements on the PFD. Pilots were able to fully exercise the airspeed / altitude indicators, command markers, vertical velocity indicator (VVI), top and bottom bank indicators, and pitch scale elements on the ADI. Pilots were also able to observe and evaluate the Map symbology of the SFD.

Navigation/Approach

This task consisted of executing the ILS 2 RWY 23 approach at Pope AFB, as published in the Flight Information Publication (FLIP). The purpose of this task was to give the pilot an opportunity to assess more "typical" symbol movements that are associated with the navigation and approach phases of flight. Pilots were able to exercise and evaluate the following ADI display symbology: airspeed and altitude indicators, command markers, vertical velocity indicator (VVI), bank indicators, and pitch scale elements. They were also able to evaluate the glideslope indicator on the ADI which is only observable during the final phase of approach. On the HSI, they were given the opportunity to exercise and evaluate the bearing pointers, heading marker, and course deviation indicator (CDI). They were also able to observe and evaluate the expanded HSI symbology on the SFD.

Data Collection

Data collection consisted of administering four questionnaires to all participating pilots at various points throughout both testing sessions. All questionnaires are presented in Appendix A.

Questionnaires addressed two major areas of investigation: 1) the effects of display type on *useability* and 2) the effects of display type on *image quality*. The following sections describe each questionnaire in the order that they were first administered.

Image Anomaly Questionnaire

The first questionnaire administered to the subject pilots was the Image Anomaly Questionnaire. The Image Anomaly Questionnaire addressed image quality issues. This questionnaire was administered as a structured interview and was verbally given to the pilots during the observation period of each evaluation task. Verbal responses were video taped recorded.

Subjects were asked to identify and describe any image anomalies that they observed on both the PFD and SFD formats. The following five categories were defined to guide their responses:

- Symbol Distortion (e.g., stair-stepping, lack of clarity/sharpness, smearing)
- Symbol Movement Anomalies (e.g., ratcheting)
- Symbol Color Anomalies (e.g., color contrast, color purity, color variations)
- Brightness Anomalies (e.g., brightness contrast, roping, brightness variations across displays or symbols)
- Anomalies associated with Flicker, Jitter or Noise

These categories were based on the results of a review of image quality characteristics that apply to both AMLCDs and CRTs. If any anomalies were reported, subjects were asked to rate their severity on a five point scale, ranging from a minor annoyance through totally objectionable.

Symbol Element Questionnaire

Following the Image Anomaly questions, a written Symbol Element Questionnaire was administered to the subject pilots as they were observing the PFD

and SFD formats (copilot was flying). The Symbol Element Questionnaire addressed useabilty issues. Pilots rated the usability of each symbol element on the PFD and SFD formats for both the CRT and AMLCD. The ratings were made based on a five-point scale that ranged from "completely acceptable" to "completely unacceptable."

Session Questionnaire

The Session Questionnaire was administered upon the completion of each testing session (i.e., AMLCD or CRT). The Session Questionnaire addressed both image quality and useability issues. This questionnaire consisted of a written form that asked the subject to rate the acceptability (using the same five-point acceptability scale as the Symbol Element Questionnaire) of various tasks within three major functional categories: formation flying, instrument flying, and navigation / approach. These categories roughly corresponded to the three task segments of the flight profile used during data collection. In addition, subjects were asked to rate the acceptability of various image quality parameters of the major display components on the PFD (i.e., ADI, HSI, Airspeed Indicator, VVI, Altitude Indicator) and SFD pages (SFD Map, SFD HSI, SFD SKE).

Final Questionnaire

The Final Questionnaire was administered upon completion of both the AMLCD and CRT simulator flying sessions. The Final Questionnaire addressed both image quality and useability issues. Subjects were asked to directly compare image quality and instrument useability between the two tested display types on a five-point preference scale. The scale values were: strongly prefer CRT, moderately prefer CRT and no preference, moderately prefer LCD and strongly prefer LCD. Also, the subjects were asked to describe what they liked and disliked about each display.

RESULTS

The questionnaire results were grouped into two broad categories for purposes of reporting: 1) ratings and comments relevant to display *usability* and pilot performance, and 2) ratings and comments relevant to display *image quality*.

Frequency distributions and means were generated for the "acceptability" and "preference" rating scale data. Complete questionnaire responses, including scale data means, frequencies and summarized verbal responses and comments, are included in Appendix B.

The "acceptability" data, collected from the Session and Symbol Element Questionnaires, used the following numerically encoded five-point scale:

5 = Completely Acceptable

4 = Moderately Acceptable

3 = Borderline

2 = Moderately Unacceptable

1 = Completely Unacceptable

The "acceptability" data were analyzed in two ways. First absolute ratings were summarized to determine the *useability* of the display types to support various tasks and to assess the *image quality* on several different parameters. Then, statistical tests were conducted on the data to determine if significant differences existed between the test AMLCD and the test CRT.

The "preference" data, collected from the Final Questionnaire, was numerically encoded as follows:

5 = Strongly Prefer LCD

4 = Moderately Prefer LCD

3 = No Preference

2 = Moderately Prefer CRT

1 = Strongly Prefer CRT

The "preference" data were analyzed in the same manner as the "acceptability" data.

Since the C-141 full mission evaluation (Toms, Cone, *et al., 1995*) and the current study employed similar questionnaires and the same formats (i.e., PFD and SFD) were used in both studies, it was possible to directly compare ratings between the two studies. Statistical tests were performed to determined if significant differences existed between the CRT used in the full mission study and the AMLCD used in the current study. This opportunity provided an additional test of the ability of the C-141 evaluation findings to generalize to AMLCD hardware.

Effects of Display Type on Useability

Absolute ratings of display useability data were averaged across subjects to determine their ability to support the flying tasks. Data for these analyses were obtained from the "acceptability" ratings of the Symbol Element and Session Questionnaires. Wilcoxon Matched Pairs Signed-Ranks tests were conducted to determine if any significant differences existed between the test AMLCD and the test CRT. Kolmogorov-Smirnov Goodness of Fit Tests were applied to the "preference" data of the Final Questionnaire to determine if one display type (i.e., AMLCD or CRT) was statistically preferred over the other.

It was recognized that symbol design would have a strong effect on useability. However, symbol design deficiencies would contribute equally to CRT and AMLCD useability ratings. Therefore any differences in the ratings should reflect the contribution of image quality differences between the two display types.

Symbol Element Useability

Pilot ratings from the Symbol Element Questionnaire showed relatively low ratings (i.e., below "moderately acceptable") for several display elements for both display types, including the flight path marker and the vertical deviation. Comments indicated that these ratings were a result of symbology design, rather than image quality, and were consistent with the findings in the C-141 full mission evaluation (Toms, Cone *et al.*, 1995). The Wilcoxon tests showed no statistically significant differences between the CRT and AMLCD symbol element ratings. However, several trends showed that pilots preferred the SKE range rings and the SFD status annunciations on the AMLCD. Comments indicated that these findings were due to the test AMLCD's sharper and crisper appearance compared to the test CRT display.

Functional Support

The results obtained from the Session Questionnaire showed that pilots rated the ability of the formats to support all functions within the three major functional categories (i.e., formation flying, instrument flying, and navigation/approach) between "moderately" and "completely" acceptable. Overall acceptance ratings for the three functional categories are depicted in Figure 5.

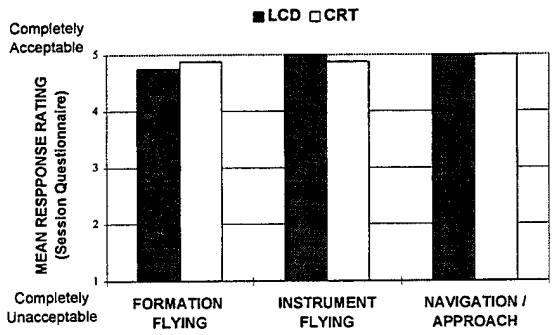


Figure 5. Overall Acceptability Ratings for Functional Categories.

The Wilcoxon tests showed no significant differences between the CRT and AMLCD for any of the tasks within each of the three functional categories. However, a trend ($p < 0.11$) showed that pilots thought the AMLCD supported maintaining vertical formation position better than the CRT display. Pilots commented that the image was much sharper on the AMLCD than on the CRT, which helped to improve the distinguishability of symbols on the vertical deviation indicator.

Instrument Display Useability

When asked to compare "overall useability" of the formats displayed on the AMLCD and CRT, 7 of the 8 subjects commented that they either "moderately preferred" (5 subjects) or "strongly preferred" (2 subjects) the AMLCD over the CRT display. These results are depicted in Figure 6.

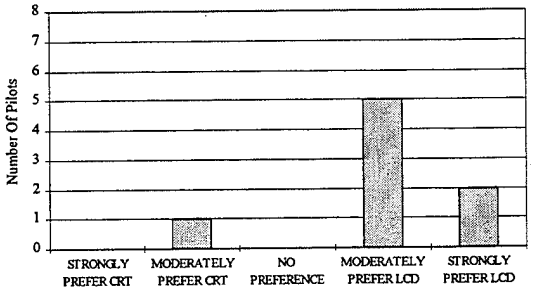


Figure 6. Subjective Preferences for Overall Usability

Comments indicated that the AMLCD was more preferred because of its relative sharpness and clarity compared to the CRT. Although this result was shown to be statistically significant, $z = 2.03$, $p < 0.01$, this finding must be considered in light of

the other questionnaire results (i.e., Symbol Element, Session) that showed that performance was adequately supported with both display types.

The Kolmogorov-Smirnov test also indicated that subjects preferred the ADI and HSI on the AMLCD over the CRT, $z = 1.67$, $p < 0.01$ and $z = 1.67$, $p < 0.01$, respectively. Once again, comments indicated that this preference was due to the relatively sharper image portrayed on the AMLCD when compared to the CRT. No significant differences were found between the AMLCD and CRT for the barometric altimeter and airspeed indicators on the PFD; or for any of the SFD format pages (i.e., Map, Expanded HSI, SKE).

Effects of Display Type on Image Quality

As with the useability data, absolute ratings of display image quality were averaged across subjects for each test display type. These data were obtained from the "acceptability" image quality ratings of the Session Questionnaire. Wilcoxon Matched Pairs Signed-Ranks tests were conducted on these data to determine if any significant differences existed between the test AMLCD and test CRT. Kolmogorov-Smirnov Goodness of Fit Tests were applied to the "preference" image quality data of the Final Questionnaire to determine if one display type (i.e., AMLCD or CRT) was statistically preferred over the other. Responses and ratings obtained from the Image Anomaly Questionnaire were summarized.

Image Quality Parameters

As shown in Figure 7, both displays received high ratings on all image quality parameters, except off-axis viewability on the AMLCD.

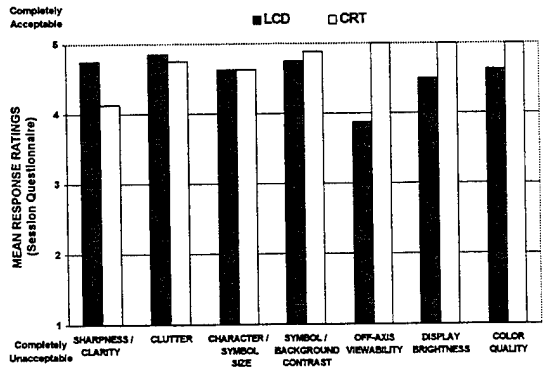


Figure 7. AMLCD / CRT Image Quality Comparisons

These data were obtained from the Session Questionnaire.

The Wilcoxon tests showed no statistically significant differences between the AMLCD and CRT, however, several image quality trends were identified. These trends can be seen in Figure 7.

One trend showed that pilots found the test AMLCD to provide a *sharper image* than the test CRT. Comments indicated that subjects preferred the AMLCD because of its sharpness and clarity compared to the CRT image which was considered to be "fuzzy."

Not surprisingly, another trend indicated lower ratings for off-axis viewability on the test AMLCD than on the CRT. Comments indicated that image contrast on the AMLCD appeared to degrade with even small head movements. This was due to the rotation of test AMLCD that resulted in a reduced lateral viewing angle (from +/- 40° to +/- 20°), and was known prior to testing.

The Wilcoxon tests also showed a trend indicating *display brightness* was slightly less acceptable on the AMLCD than on the CRT. Comments from two subjects indicated that both displays, as set in the study, were too bright for night flying. Subject comments suggest that the test AMLCD's brighter "black" background may have enhanced this effect (as an experimental control, subjects were not permitted to adjust the display brightnesses). Another trend showed that color quality was slightly less acceptable on the test AMLCD than on the test CRT. Pilot comments indicated that this was primarily due to the desaturation of the AMLCD colors compared to the colors on the CRT.

Image Anomaly Observations

In response to verbal questions on image anomalies (during the observation period), image anomalies were observed on both the AMLCD and CRT. These anomalies fell into the categories of color characteristics, luminance characteristics and symbol and motion distortions. All anomalies reported were considered to be a minor or moderate annoyance and would not affect the useability of the display or task performance.

Color anomalies were observed on both display types. On the AMLCD, 3 of the 8 subjects reported

color banding artifacts on some numbers and letters. Six subjects reported a blending of colors or reduced color contrast on the AMLCD. In particular, the white lines of the pitch scale had a reduced contrast against the ADI brown background. The magenta command bars and heading marker symbols had relatively low contrast against their respective gray and black backgrounds. Also the yellow pitch steering bar and SKE annunciation were difficult to discriminate against their respective ADI brown and blue backgrounds. On the CRT, 6 subjects reported color contrast anomalies. As on the AMLCD, pilots reported that contrast between the yellow SKE indicator and yellow steering bar was degraded against the ADI blue and brown backgrounds. Subjects also reported that the color of the SKE format range rings were not uniform across the CRT display.

Luminance anomalies were reported on both display types. On the AMLCD, 7 out of 8 subjects observed "roping" image anomalies, in which the line appeared non-uniform in luminance, and flickering with some symbols on the AMLCD. Roping was primarily observed on the pitch lines, and bank and pitch steering bars. Also the bank steering bar and some lettering appeared to flicker somewhat. On the CRT, this effect was not as prominent. Roping was observed by 4 subjects and only on the bank steering bar.

Symbol distortion and movement anomalies were also reported for both display types. Six subjects reported observing symbol distortions and movement anomalies on the AMLCD. In particular, stair-stepping was reported on the course deviation and pitch scale lines. Also the course arrow and several numbers were reported as having some jitter movement. However, pilots felt these anomalies were not objectionable and would not degrade performance. Other than a general fuzziness of the symbols and a flickering of the Course Deviation Indicator, there were no comments regarding symbol distortion on the CRT.

Image Quality Preferences

The Kolmogorov-Smirnov tests showed that subjects preferred the test AMLCD to the test CRT display, $z = 2.03$, $p < .01$. Again comments indicated this was primarily due to the sharper, crisper appearance of the AMLCD image compared to the fuzziness of the CRT image. The Kolmogorov-Smirnov tests also showed that image quality in static conditions, $z = 1.67$, $p < .01$ was preferred with the AMLCD. No significant differences between display types regarding image quality in dynamic conditions were found.

Five of the eight pilots commented that the CRT's fuzziness could cause some fatigue with extended use. In general, however, pilots felt that the image quality of either display would be acceptable for transport cockpit applications.

Comparison to the Full-Mission Simulation Findings

Mann-Whitney U tests were applied to the between-study comparisons to determine if significant differences existed between those ratings obtained in the Full Mission Evaluation (Toms, Cone, *et al.*, 1995) and those obtained with the AMLCD in the current study. The results showed no significant differences between the two studies. Although some indication that instrument flying tasks were rated lower in the current study than in the full mission evaluation, these trends can be best explained by task differences that existed between the two studies. Caution should be exercised in making comparisons between the two studies because each study's emphasis was different. The full mission study emphasized format issues and performance, whereas in the current study, the subjective assessment of image quality was emphasized over performance.

DISCUSSION

The results of the study indicated that both the tested CRT and AMLCD format implementations provided acceptable image quality to support transport aircraft flying tasks. Pilots rated the ability of the formats to support *all* of the functions above "moderately acceptable." These results suggest that the proposed C-141 formats *can* be implemented on AMLCD hardware without any significant degradation to image quality or useability. Although image anomalies and artifacts were observed on both displays, they were considered to be relatively minor annoyances that would not degrade pilot performance. This is in agreement with other research that has found no adverse performance effects with such anomalies as stair-step distortions (Uphaus, *et al.*, 1989).

Image sharpness was shown to have strongly influenced the results. When compared to other image quality dimensions such as color quality, contrast, and luminance characteristics, the results indicated that image sharpness was more heavily weighted and a predominant factor for determining overall useability.

The results suggest that formats developed on the CRT can adequately predict performance on an AMLCD. That is, previous findings obtained with the CRT during the Preliminary and Full-Mission evaluations can be generalized to an AMLCD. No significant differences were found between the test CRT and AMLCD regarding display useability. The between-study comparisons, which also showed no significant differences, lend additional confidence to this generalization of results.

For future CRT to AMLCD implementations, the results suggest that the CRT may be an effective prototyping tool for developing formats intended for AMLCD use. However, caution must be exercised when generalizing these results to other CRT to AMLCD format conversion efforts, particularly if the hardware imaging characteristics and significantly differ from those used in the current study. For example, if spot sizes between the display types are considerably different (they were similar in the current study), formats may not transfer over as easily from one display type to another. Also, the same antialiased video signal was used on the test AMLCD and CRT; and it is possible that the same antialiasing method can produce different results on different display types.

In addition, one must consider the formats used in the current study when generalizing results. The tested formats were symbolic in nature, used color conservatively as a redundant coding method, and were not highly dynamic. The impact of CRT and AMLCD differences may become significantly exaggerated in formats that radically differ from the PFD and SFD, such as those that rely heavily on extensive use of video, color, or highly dynamic symbology.

Both test displays (i.e., CRT and AMLCD) were of commercial quality and not intended for military applications. A similar study using military equipment may have produced different results. For example, if the CRT had used stroke symbology, as is often used in military CRTs, it is possible that subjects may have rated the image sharpness of the CRT differently.

Also to be considered are the image quality tradeoffs that may occur when designing to stringent military specifications. Enhancing one image quality dimension to meet design specifications may be at the expense of other image quality dimensions. For example, increasing lateral off-axis viewing for cross-cockpit viewing may degrade other image quality dimensions (e.g., overall color contrast).

Format Design Considerations

While this study was primarily interested in image quality and useability of the displays, we recognized that subjects may find it difficult to separate those dimensions from format design. Therefore we did not discourage any comments regarding the design of the formats. Format design comments were consistent with those obtained in the full mission study (Toms, Cone *et al.*, 1995). Pilots expressed concern with the digital readouts, especially in extracting altitude trend information from the PFD. They also expressed concern with the rate of movement on the digital baro altimeter which slows down at a preset rate of climb or descent (i.e., when vertical velocity exceeds 1800 feet per minute, the digital readout changes from 10 foot increments to 100 foot increments). Pilots also considered the relative range indicator to be too cluttered and in too close proximity to the other symbol elements. It should be noted though, that both studies showed that the formats supported all tasks.

Optimizing AMLCD Formats

The results of this study highlight the need to consider the intent of the design when converting formats from a CRT to an AMLCD. Directly transitioning the C-141 formats from a CRT to an AMLCD may not result in an *optimized* format on the AMLCD. In the current study, minor luminance nonuniformities, shape distortions, and reduced color contrast effects were observed. A variety of issues should still be addressed when developing formats that are intended for implementation on an AMLCD. Of course, the major goal of transitioning formats from one display to another is to ensure the intent of the design is maintained and that the formats are doing what they were designed to do. We've identified

three major categories that should be considered when implementing the proposed C-141 flight formats on an AMLCD: color characteristics, luminance characteristics and motion/spatial characteristics. Each will be discussed in more detail in the following sections.

Color Characteristics

Because color contrast greatly influences symbol discriminability, it is important that color contrast characteristics, found to be adequate with the CRT, are not lost when formats are implemented on the AMLCD. If CRT colors are chosen to be maximally discriminable in dark ambient conditions, then some of the CRT colors may not be replicated on the AMLCD due to its reduced chromaticity envelope.

The desaturation of colors on the AMLCD were shown to result in some observed symbol/background contrast reduction. In particular, the magenta command bars and heading marker symbols had relatively low contrast against their respective gray and black backgrounds. Also, the white lines of the pitch scale had a reduced contrast against the ADI brown background, and the yellow pitch steering bar and SKE annunciation were difficult to discriminate against their respective ADI brown and blue backgrounds.

Another consideration regarding color choice is the potential impact of colors shifting with changes in viewing angle. Off-axis viewing is still one of the biggest challenges facing AMLCDs and will have a significant impact on its acceptability for transport cockpit applications. This importance dictates the need to establish an understanding of the nature of the color shifts (e.g., chromaticity, luminance) as a function of viewing angle (magnitudes), so that tolerances can be established. Simulation studies, such as those conducted in the current study, are necessary to determine the implications of these established tolerances for performance.

Luminance Characteristics

It is also important that the luminance contrast characteristics of the CRT are maintained with format conversions to the AMLCD, and that no new anomalies are created that will degrade the image. In this study, luminance contrast of the various display colors was not controlled between the two display types (only overall display luminance). For most of the colors, the luminance differences between the CRT and AMLCD were minimal. However, in other AMLCD applications, this characteristic could affect the perceived priority of the symbology (e.g., brighter or dimmer symbols can be perceived to be respectively more or less important than other display symbols).

Methods used for highlighting should be selected carefully when formats are transferred from CRT to AMLCD. The use of bolding through double stroking, a common highlighting method used on CRTs, cannot be implemented on AMLCDs. However, other research (Jacobsen, 1988) has found that line thickening on the AMLCD will produce the same effect and with even greater flexibility. A highlighting method that was successfully implemented in this study was the use of haloing. With this method, a black outline is created to surround a symbol. This formatting technique was shown to be effective by increasing the apparent luminance and color contrast on both the CRT and AMLCD. This effect was reported as being more pronounced on the AMLCD because of its sharper image.

Because luminance variances may differ with manufacturer, it is a factor to considered when establishing the color luminances to be used in instrument symbology. The black and brown colors were quite different between the test AMLCD and the CRT. This effect was observed by various subjects in the current study. Although the brighter AMLCD brown background provided a good contrast for the dark symbols, some of the lighter symbols blended into the background, making them more difficult to discern. In extreme cases, this effect could significantly degrade the usability of some symbols.

Motion / Spatial Characteristics

One of the problems noted with AMLCD images are "jaggies" or line-stepping symbol distortions. Dynamic imagery may also exhibit a ratcheting appearance. Antialiasing techniques have been shown to eliminate or reduce many of these artifacts to minor annoyances. However, various antialiasing algorithms can produce different effects, such that one anti-aliasing method may be more effective in reducing these distortions than another. Various antialiasing techniques may need to be tested if motion or spatial distortions are prevalent in the display.

Although some researchers (Weidenmann, J. and Trujillo, E.J., 1993) have reported a "chopped up" symbol appearance with certain symbol priority schemes (e.g. symbol masking techniques), these were not observed in this study. In fact, several subjects reported that it was easier to break out some symbols when they interacted on the AMLCD than on the CRT (e.g., waypoint / route lines).

Several minor symbol distortions and movement anomalies were observed on the AMLCD. In particular, stair-stepping was reported on the course deviation and pitch scale lines. It is possible that these anomalies may have been more apparent on the AMLCD because of its sharper image. Other than a general fuzziness of the symbols and a flickering of the Course Deviation Indicator, there were no comments regarding symbol distortion on the CRT.

CONCLUSIONS

The results showed that the proposed C-141 Primary Flight Display and Secondary Flight Display formats could be implemented on the test AMLCD hardware with no significant degradation in image quality or usability. These results indicate that the test CRT, used in the previous evaluations, was adequate for testing the proposed formats.

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APPENDIX A

QUESTIONNAIRE FORMS

IMAGE ANOMALY QUESTIONS
(given while observing formats, copilot flying)

Subject No. _____ **Display Medium: AMLCD / CRT**

1. Do you have any initial comments regarding the image quality of the display?

2. Did you notice any **Symbol Distortion** with any of the display elements? (i.e., stair-stepping, lack of clarity/sharpness, smearing)?

____ YES _____ NO
If YES, what symbols were distorted? Rate the severity of image degradation on a 1-5 scale (1=minor annoyance, 5=objectionable).

3. Did you notice any **Symbol Movement** anomalies (i.e., ratcheting)?

____ YES _____ NO
If YES, which symbols were affected? Rate the severity of image degradation on a 1-5 scale.

4. Did you notice any image anomalies associated with **Symbol Color** (i.e., discriminability from other colors and background, color purity, variations across display screen)?

____ YES _____ NO
If YES, which symbol elements were they? Rate the severity of image degradation on a 1-5 scale.

5. Did you notice any **Brightness** anomalies (i.e., contrast between symbol and background, roping or variations across the display)? What about overall display brightness?

____ YES _____ NO
If YES, which symbols? Rate the severity of image degradation on a 1-5 scale.

6. Did you notice any image anomalies associated with **Flicker, Jitter, and Noise**?

____ YES _____ NO
If YES, which symbol elements were affected? Rate the severity of the image degradation on a 1-5 scale.

7. Any other display image quality problems? Severity Rating (1-5)

SYMBOL ELEMENT QUESTIONNAIRE
PFD & SFD SKE ELEMENTS

Subject No. _____ **Display Medium: AMLCD CRT**

Instructions: Using the scale below, please rate the useability of the following PFD and SFD SKE elements.

Rating Scale:
5 = Completely Acceptable: **Good** as is.
4 = Moderately Acceptable: **Minor annoyances** that do not impact useability.
3 = Borderline: Deficiencies that **could impact useability**; changes desirable.
2 = Moderately Unacceptable: Deficiencies that **degrade usability**; corrections required.
1 = Completely Unacceptable: Serious Deficiencies, **not useable**; major rework required.

Comments:

PFD SKE ELEMENTS:

a) ____ **SKE Vertical Deviation Indicator**
b) ____ **SKE Relative Range Indicator**
c) ____ **SKE Lateral Deviation Bar**
d) ____ **SKE Annunciation**

SFD SKE ELEMENTS:

a) ____ **SKE Ownship**
b) ____ **Master Ship**
c) ____ **Follower Ships**
d) ____ **SKE Route Line**
e) ____ **Waypoint Identifier**
f) ____ **Proximity Warning Line**
g) ____ **SKE Range Rings**
h) ____ **ETE / ETA**
i) ____ **Status Annuciations (bottom fixed data area)**
j) ____ **ZM**

SYMBOL ELEMENT QUESTIONNAIRE
SFD MAP / EXPANDED HSI ELEMENTS

MAP ELEMENTS:

Instructions: Using the scale below, please rate the useability of the following SFD elements.

Rating Scale:
5 = Completely Acceptable: **Good** as is.
4 = Moderately Acceptable: **Minor annoyances** that do not impact useability.
3 = Borderline: Deficiencies that **could impact useability**; changes desirable.
2 = Moderately Unacceptable: Deficiencies that **degrade usability**; corrections required.
1 = Completely Unacceptable: Serious Deficiencies, **not useable**; major rework required.

Comments:

a) ____ Aircraft Symbol

b) ____ Compass Rose

c) ____ Heading Marker

d) ____ Track Cross

e) ____ Course Readout

f) ____ Bearing Pointers

g) ____ Bearing Ptrs Identifier / DME

h) ____ Route Overlay / Waypoints

i) ____ Range Rings / Labels

j) ____ Status Annuciations (bottom fixed data area)

k) ____ Caution Warning Annuciations (top fixed data area)

EXPANDED HSI ELEMENTS:

Instructions: Using the scale below, please rate the useability of the following SFD elements.

Rating Scale:
5 = Completely Acceptable: **Good** as is.
4 = Moderately Acceptable: **Minor annoyances** that do not impact useability
3 = Borderline: Deficiencies that **could impact useability**; changes desirable.
2 = Moderately Unacceptable: Deficiencies that **degrade usability**; corrections required.
1 = Completely Unacceptable: Serious Deficiencies, **not useable**; major rework required.

Comments:

a) ____ **Aircraft Symbol**

b) ____ **Compass Rose**

c) ____ **Heading Marker**

d) ____ **Track Cross**

e) ____ **Course Readout**

f) ____ **Bearing Pointers**

g) ____ **Bearing Ptrs Identifier / DME**

h) ____ **Course Arrow**

i) ____ **Course Deviation Indicator / Scale**

j) ____ **Status Annuciations (bottom fixed data area)**

k) ____ **Caution Warning Annuciations (top fixed data area)**

l) ____ **To / From Indicator**

SYMBOL ELEMENT QUESTIONNAIRE
PFD ELEMENTS

Subject No. _____ **Display Medium: AMLCD CRT**

Instructions: Using the scale below, please rate the useability of the following PFD elements.

Rating Scale:
5 = Completely Acceptable: **Good** as is.
4 = Moderately Acceptable: **Minor annoyances** that do not impact useability.
3 = Borderline: Deficiencies that **could impact useability**; changes desirable.
2 = Moderately Unacceptable: Deficiencies that **degrade usability**; corrections required.
1 = Completely Unacceptable: Serious Deficiencies, **not useable**; major rework required.

ADI ELEMENTS:

Comments:

a) ____ Miniature Aircraft Symbol

b) ____ Climb-Dive Marker

c) ____ Pitch Scale

d) ____ Bank Pointers / Scales

e) ____ Bank Steering Bar

f) ____ Pitch Steering Bar

g) ____ Glideslope Deviation Indicator

h) ____ Rising Runway

i) ____ Speed Worm

j) ____ Flight Path Angle (dotted line)

k) ____ MDA / DH Annunciations

HSI ELEMENTS:

Comments:

a) ____ Aircraft Symbol

b) ____ Compass Rose

c) ____ Heading Marker

d) ____ Track Cross

e) ____ Course Readout

f) ____ Bearing Pointer 1

Rating Scale:

5 = Completely Acceptable: **Good** as is.
4 = Moderately Acceptable: **Minor annoyances** that do not impact useability.
3 = Borderline: Deficiencies that **could impact useability**; changes desirable.
2 = Moderately Unacceptable: Deficiencies that **degrade usability**; corrections required.
1 = Completely Unacceptable: Serious Deficiencies, **not useable**; major rework required.

Comments:

e) ____ **Bearing Pointer 2**

f) ____ **Bearing Ptr 1 Identifier / DME**

g) ____ **Bearing Ptr 2 Identifier / DME**

h) ____ **Course Arrow**

i) ____ **Course Deviation Indicator / Scale**

j) ____ **To / From Indicator**

AIRSPEED ELEMENTS:

a) ____ **Airspeed Scale**

b) ____ **Digital Readout**

c) ____ **Mach Indicator**

d) ____ **"Bowtie" Command Marker**

e) ____ **Command Digital Airspeed Readout**

ALTITUDE ELEMENTS:

a) ____ **Altitude Scale**

b) ____ **Digital Readout**

c) ____ **"Bowtie" Command Marker**

d) ____ **Radar Altimeter Thermometer**

e) ____ **Vertical Velocity Indicator**

f) ____ **Baro Altimeter Setting**

g) ____ **Altitude Alert Readout**

SESSION QUESTIONNAIRE

(given after each testing session)

Subject Number:_____ **Date:**_____

Display Medium (Circle One): AMLCD / CRT

Instructions. Use the scale below to rate how well the display supports the following tasks. Please provide comments for any item rated "borderline or worse" (i.e., 3, 4, 5.).

Rating Scale:

5 = Completely Acceptable: **Good** as is.
4 = Moderately Acceptable: **Minor annoyances** that do not impact performance.
3 = Borderline: Deficiencies that **could impact performance**; changes desirable.
2 = Moderately Unacceptable: Deficiencies that **degrade performance**; corrections required.
1 = Completely Unacceptable: Serious Deficiencies, **can not perform intended function**; major rework required.

COMMENTS:

---

1. BASIC INSTRUMENT FLIGHT TASKS

a) ____ Determine ground track
b) ____ Determine pitch
c) ____ Determine aircraft bank
d) ____ Determine vertical velocity
e) ____ Determine heading
f) ____ Acquire airspeed trend information
g) ____ Acquire altitude trend information
h) ____ Capture/Maintain altitude
i) ____ Capture/Maintain airspeed
j) ____ Capture/Maintain heading
k) ____ Overall basic flight instrument tasks

2. NAVIGATION / APPROACH TASKS

a) ____ Fly a Standard Instrument Departure (SID)
b) ____ Navigate using radio-based Navaids
c) ____ Acquire and maintain course
d) ____ Fly an ILS approach
e) ____ Overall navigation tasks

3. SKE TASKS

a) ____ Maintain Relative Range
b) ____ Maintain Vertical Distance
c) ____ Maintain Lateral Distance
d) ____ Overall SKE Formation Flying Tasks

4. OTHER TASKS

a) ____ Maintain situational awareness
b) ____ Performing efficient cross-check
c) ____ Can be used with an acceptable level of safety in a standard operational environment

5. Do you feel that this display configuration can effectively support the following missions?

	YES	NO	IF NO, WHY?
SOLL 2	_____	_____	_____
CAT II Approach	_____	_____	_____
Air Refueling	_____	_____	_____
Airdrop	_____	_____	_____
Airland	_____	_____	_____
Low Level Tactical	_____	_____	_____
Lengthy Missions	_____	_____	_____
Other _____	_____	_____	_____

6. Use the rating scale below to rate the following.

Rating Scale:
5 = Completely Acceptable: **Good** as is.
4 = Moderately Acceptable: **Minor annoyances** that do not impact performance.
3 = Borderline: Deficiencies that **could impact performance**; changes desirable.
2 = Moderately Unacceptable: Deficiencies that **degrade performance**; corrections required.
1 = Completely Unacceptable: Serious Deficiencies, **can not perform intended function**; major rework required.

COMMENTS:

_____

a) _____ Clutter

b) _____ Character / Symbol Size

c) _____ Off-axis Viewability

d) _____ Display Brightness

e) _____ Color Characteristics

f) _____ Symbol / Background Contrast Characteristics

g) _____ Sharpness / Clarity

h) _____ Overall Useability

7. Do you think there would be any fatigue effects using this display with prolong use? YES NO

FINAL QUESTIONNAIRE
(given after both testing sessions)

1. Please indicate your preference for the following display components.

	Strongly Prefer CRT	Moderately Prefer CRT	No Preference	Moderately Prefer AMLCD	Strongly Prefer AMLCD	WHY?
a) ADI						
b) HSI						
c) AIRSPEED INDICATOR						
d) ALTIMETER						
e) SFD SKE Format						
f) SFD Map Format						
g) SFD Expanded HSI Format						

Other Comments:

2. Please indicate your preference for the following image quality parameters.

	Strongly Prefer CRT	Moderately Prefer CRT	No Preference	Moderately Prefer AMLCD	Strongly Prefer AMLCD	COMMENTS
a) Color Characteristics						
b) Sharpness / Clarity						
c) Contrast Characteristics						
d) Brightness Characteristics						
e) Image Quality in Dynamic Conditions						
f) Image Quality in Static Conditions						
g) OVERALL USEABILITY						

3. What characteristics did you **most like** and **least like** about the **CRT?**

4. What characteristics did you **most like** and **least like** about the **AMLCD**?

5. What other characteristics about either the AMLCD or CRT display do you feel may impact its usability in operational conditions?

6. Did you feel that flying position (i.e., right seat, left seat) affected your assessment of the display media (i.e., CRT / AMLCD)?

   YES NO

   If YES, in what way?

APPENDIX B

QUESTIONNAIRE RESULTS

IMAGE ANOMALY VERBAL RESPONSES

CRT

SKE TASKS - PFD:

1. **Do you have any initial comments regarding the image quality of the display?**

S1. The only thing I can think of off hand is the little aircraft on the range scale gets a little lost amiss all the little circles and letters and everything, it doesn't stand out. It could just be me but a couple of times I completely forgot about it in my cross-check. I would notice it by a tone that I was out of position or I would just remember it. If I were designing it, I would have it a little brighter, thicker white airplane. In the learning process, it would be much better of the range aircraft stood out more. So when it started moving it would catch your eye.

S2. Not as sharp as the LCD.

S3. A clarity control, it just looks a tad fuzzy. Not really distracting.

S4. Look slightly unfocused. Not as sharper as the LCD.

S5. I find the numbers to be a little fuzzy. And its not there unreadable. I think some of the symbols are small (CDM, Range, SKE Altitude). Things get lost when they get lined up.

S6. Pretty amazing, how smearing and fuzzy everything looks.

S7. It's good, readable, and colors are meaningful.

S8. Overall much fuzzier on every aspect than LCD was.

2. **Did you notice any Symbol Distortion with any of the display elements? (i.e., stair-stepping, lack of clarity/sharpness, smearing)?**

S2. NO: Just that everything is a little fuzzier than the other.

S6. YES: Rating of 2. The whole screen is smeary. I'd have to think they're all fuzzy.

S7. NO. Basic design of format is that little airplane on SKE range symbol is too small, although nothing to do with CRT.

S8. NO, as far as something being distorted to the point of not using it. No not really. Some numbers like altimeter setting, I'd like it to be a little larger. Same thing is true with primary heading indicator on HSI since they're fuzzier, I would like for them to be larger. Also with altitude and readout.

3. **Did you notice any Symbol Movement anomalies (i.e., ratcheting)?**

S3. NO: Overall pretty smooth.

S4. YES: Still get the flicker with the outline of bank steering bar.

S5. YES: The bank steering bar jumps.

S6. YES: Rating of 2. Bank Steering Bar flashing.

S8. YES: Rating of 2. Bank Steering Bar still doing dark/light - dark/light. Pitch lines not rastering like on LCD.

4. **Did you notice any image anomalies associated with Symbol Color (i.e., discriminability from other colors and background, color purity, variations across display screen)?**

S1. YES: Rating of 1. I think everything looks fine. I would consider making the steering bars more vivid yellow, just so it would catch your attention more. But it is nothing bad. It's just a little thing.

S2. YES: Rating of 3. The bowtie seems to stick out more. Not all even. Its sort of unnatural. Some colors sticking out more than.

S5. NO: Colors good, real well defined.

S6. YES: Rating of 3. Little airplane on the SKE range blends in with white scaling.

S7. NO. All colors seem to stand out, no blending in.

S8. As far as contrast from surrounding colors. Fine. Same comments with RANGE label, get rid of. Whole region jam backed with information. Same with altitude deviation off lead. Rating 3.

5. Did you notice any Brightness anomalies (i.e., contrast between symbol and background, roping or variations across the display)? What about overall display brightness?

S2. NO: Its a little bright for me for night flying.

S3. NO: Overall seems good.

S5. NO: The CDM needs better contrast, it blends in.

S6. NO. Brightness-wise OK. Brightness is not too bright like LCD. However, if you flew for a few hours, probably all too bright.

S7. NO It's good. If I had an adjustor, I'd make the whole thing a tad brighter. It's useable the way it is.

6. Did you notice any image anomalies associated with Flicker, Jitter, and Noise?

S4. And the SKE annunciator and scale the same as the LCD. Need to give priority to the scale.

7. Any other display image quality problems? Severity Rating (1-5)

S1. I don't know if I would call it a problem but the way the altimeter works, when it starts moving in 10 foot per minute increments, the altitude seems to be changing rapidly then it switches to 100 foot increments, it becomes disorienting and you feel like your rate of altitude climb or descent has slowed down where actually it has sped up. The faster you go up or down the slower the numbers move. That is a little disturbing me.

TASKS - SFD SKE Format:

1. Do you have any initial comments regarding the image quality of the display?

S1. I think it is well represented. I think it is extremely easy to understand, everything makes sense. I don't have anything negative about this one at all.

S3. A clarity control, it just looks a tad fuzzy. Not really distracting.

S4. Not as sharp as LCD. Readable.

S5. I find the numbers to be a little fuzzy. And its not there unreadable. I think some of the symbols are small (CDM, Range, SKE Altitude). Things get lost when they get lined up.

S6. Doesn't seem as clear as the other one.

S8. Overall much fuzzier on every aspect than LCD was.

2. Did you notice any Symbol Distortion with any of the display elements? (i.e., stair-stepping, lack of clarity/sharpness, smearing)?

S8. NO. Not really, although (symbols) fuzzy, still retain inherent meaning.

S5. YES: Rating of 1. Sharpness is fuzzy.

3. Did you notice any Symbol Movement anomalies (i.e., ratcheting)?

S3. NO: Overall pretty smooth.

S5. YES: Rating of 1. The airplane behind is ratcheting.

4. Did you notice any image anomalies associated with Symbol Color (i.e., discriminability from other colors and background, color purity, variations across display screen)?

S1. NO: The colors were really good. The prox line was really nice, the color of that really stands out from everything.

S2. NO. I notice the range rings a little two-tone in appearance.

S3. NO: Seems good overall.

S4. NO: A little bit variation in the ring colors not as sharp of contrast.

S6. NO It's fine. Upper and lower quadrant differ colors on range rings.

5. Did you notice any Brightness anomalies (i.e., contrast between symbol and background, roping or variations across the display)? What about overall display brightness?

S1. YES: The circles are a little dim, I don't know if that is good or bad. They certainly don't need to be very bright just as long as you can make them out.

S2. NO: Not so bad because of dark background.

S3. NO: Overall seems good.

6. Did you notice any image anomalies associated with Flicker, Jitter, and Noise?

S4. NO: Has same jittering on 3 as LCD.

S8. NO. # 3 jumps.

7. Any other display image quality problems? Severity Rating (1-5)

S1. The altitude down here is really a little annoying that the number's are changing so fast. If your at 6210 if the last 2 digits would only change in increments of 10 that would be fine.

PRECISION FLYING TASKS - PFD:

1. Do you have any initial comments regarding the image quality of the display?

S1. None at this time.

S2. NO: Just the overall fuzziness but is still good. But not as much roping as on LCD.

S3. A clarity control, it just looks a tad fuzzy. Not really distracting.

S5. Its less cluttered and easier to read. Didn't notice shadowing before on tapes. Seems crisper, maybe because I am just getting use to it.: Rating 1

S5. 2 bearing pointers do not have good contrast between them. DME seem

S6. Nothing different in image quality.

S8. Flight Path Marker a big pain. Big L shaped thing that is my airplane, I don't use. The thing that I'm using is the little black dot that moves around. The most amount of information you get off display is flight path marker. And what is worse on the CRT is that it is fuzzy, so it looks like a black dot. Especially when it is on the brown background. When it moves behind aircraft symbol almost completely lost it. Need bigger numbers -almost significantly bigger numbers.

PRECISION FLYING TASKS - SFD MAP Format:

1. Do you have any initial comments regarding the image quality of the display?

S2. Its pretty nice.

S3. Overall good. The stat air temp and true airspeed as a constant indicator in front of me is semi-useful. A clarity control, it just looks a tad fuzzy. Not really distracting.

S4. Slightly blurry. Radar altitude is distracting.

S6. It looks fine. I don't find the MAP display very useful.

S8. First thing that catches my eye is the altitude digital readout. Still a problem. Track cross is too small. Gets lost on compass rose scale when on inside. Lose it over scale, especially with numbers.

2. Did you notice any Symbol Distortion with any of the display elements? (i.e., stair-stepping, lack of clarity/sharpness, smearing)?

S7. NO. Waypoints 9 & 10 (symbol by the numbers) kind of get hidden by lines. Nothing to do with CRT though.

S8. NO General fuzziness of symbols. Radial DME fix, circle with line through it, can't see it right now.

3. Did you notice any Symbol Movement anomalies (i.e., ratcheting)?

S3. NO: Overall pretty smooth.

S5. Heading bug not the smoothest, when you're setting it is jittering.

4. Did you notice any image anomalies associated with Symbol Color (i.e., discriminability from other colors and background, color purity, variations across display screen)?

S2. NO: Seems fine, same as LCD.

S6. NO Other than magenta, I don't like magenta.

S7. YES. Rating 2. Green numbers at fixed data area on bottom are hard to read, blend into the rest of the display - green range rings.

S8. NO. Color OK, Contrast OK

5. Did you notice any Brightness anomalies (i.e., contrast between symbol and background, roping or variations across the display)? What about overall display brightness?

S2. NO. Fine with dark background.

S6. NO. Same as before, after a period of time the display would get too bright.

S8. NO. Intensity right level.

6. Did you notice any image anomalies associated with Flicker, Jitter, and Noise?

PRECISION FLYING TASKS - SFD EXPANDED HSI Format:

1. Do you have any initial comments regarding the image quality of the display?

S1. It is very nice to have something so big and bright.

S3. Pretty nice.

S4. Slightly blurry. Radar altitude is distracting.

S5. Still a little fuzzy.

S6. Again, with the CRT, image quality seems kind of distorted, fuzzy.

S8. Overall fuzziness, again. Specific to the display, would like DME to be bigger, even if not fuzzy. Altitude too sensitive at one foot level, don't need.

2. Did you notice any Symbol Distortion with any of the display elements? (i.e., stair-stepping, lack of clarity/sharpness, smearing)?

S8. YES Rating 1. Number 2 is alot clearer on BP 2 in upper right (identifier) than on compass rose pointer which is still attached. That six (upper right) would be better on BP head. Also #2 and #1 should be orientated to me (in up position) so I wouldn't have to look at it upside down.

3. Did you notice any Symbol Movement anomalies (i.e., ratcheting)?

No responses

4. Did you notice any image anomalies associated with Symbol Color (i.e., discriminability from other colors and background, color purity, variations across display screen)?

S5. YES: Rating of 1. The colors all blend together on the bearing pointers when they are overlaying each other.

5. Did you notice any Brightness anomalies (i.e., contrast between symbol and background, roping or variations across the display)? What about overall display brightness?

No Responses

6. Did you notice any image anomalies associated with Flicker, Jitter, and Noise?

No Responses

NAV / APPROACH TASKS - PFD:

1. Do you have any initial comments regarding the image quality of the display?

S1. Initially having your barometric altimeter spinning and your AGL spinning right under it is just a little confusing to me when I look at those number's. I am just probably use to seeing this one where the pointer matches it. Its just not as much info with out a pointer showing you how close you are to the ground. And it may be because I'm just not use to it. I just want to see changes go in at the same time when I'm looking at all the other info and figuring out where I am and how I I'm doing. When I see both of these number's moving, I found myself having to think about it, which ones is which, how high I am from the ground. All my trend was coming from the baro here and the VVI. That was enough and I used the radar altimeter as a third reference for how high I am from the ground. Just a little trouble with only the numbers.

S3. The only thing was the switching of the altimeter between 10's and 100's. Overall the picture itself is good.

S4. NO: Is good. The blue for #2 is sharper than on LCD.

S7. YES: Rating of 2. Pitch Steering Bar a little subdued. Needs to be a little more prominent, maybe a little brighter.

S8. Overall fuzziness is starting to bother my eyes. The flight path marker, that fact that I'm using it more on approach, is so small is a big pain especially on the brown (ADI). Overall fuzziness a problem.

IMAGE ANOMALY VERBAL RESPONSES

LCD

SKE TASKS - PFD:

1. Do you have any initial comments regarding the image quality of the display?

S1. I like this alot, even better than the other one just in general because the contrast of some of the imagery on top of the ADI. The HSI's pretty much look the same but on the ADI the course steering bar, the aircraft, and your turn symbols are all outlines in black, and it shows up so much better than the other one. And I can see it very easily.

S2. Once, I got used to it. I think I really liked it. Its really clear. If compare it to the central screen, its much sharper.

S3. I like it better than the CRT. It is clearer on the lines, makes it easier to read.

S4. Its all readable and easy to see here in the SKE mode.

S5. It seems sharper to me. As you move around you get a different reflection.

S6. The quality is all right.

S7. If you hold your head still its OK. It's useable, but contrast and everything else changes with side to side viewing angle. Where I'm sitting, right in back of the yoke, it's not quite as bright or as clear as if I over 3 or 4 inches (to the left).

2. Did you notice any Symbol Distortion with any of the display elements? (i.e., stair-stepping, lack of clarity/sharpness, smearing)?

S2. YES: Rating of 1. If I move my head around little, the screen seems to glow. Its mostly on the ADI like this line here. Can see darker spots running on it or when it turns on a bank, mostly the 10 degree down line in the brown area. Wouldn't even notice it unless you are looking for something to critique.

S4. Rating of 2. YES: The bank steering bar the outline seems to get thicker as it moves across. Doesn't stay a steady picture, almost like it is flipping over as it moves across the screen. It's not unreadable is just not perfect.

S5. YES: Rating of 1. Stair stepping with CDI and the pitch lines, arrows, and numbers.

S8. YES. Rating of 2. Number 2 in BP 2 where 2 comes down and meshes with the side. Minor annoyance.

S8. Rating 1: The word 'range' stair steps.

3. Did you notice any Symbol Movement anomalies (i.e., ratcheting)?

S2. NO: The diamond on the right and the circles, you notice these when they move and you can correct to them. But when it sits still it doesn't jump out at you and you really

have to pay attention to it to keep it in your cross-check when your straight and level.

S4. NO: Seemed smooth and fluid.

S6. Nothing, I didn't cause. The only thing I noticed which is kind of distracting is the bank steering bar. It kind of flashes at you. Rating: 1.

S7. YES: Rating of 2. Bank Steering Bar kind of jumping in and out. Is that roping?

S8. YES. Rating 1: White lines that indicate your pitch in degrees (5,10,15,20), those as you go up and down tend raster a litter. Gives a rastering appearance.

4. Did you notice any image anomalies associated with Symbol Color (i.e., discriminability from other colors and background, color purity, variations across display screen)?

S2. NO: The ADI you can definitely read the numbers in the blue area better than in the brown area.

S3. NO: Like the ADI brown on the CRT better. I like the purple shading behind the altitude and airspeed scales. Image clarity is better than the CRT (in SKE Range, VVI).

S4. YES: Rating of 2. Its pretty easy to see. The one thing that blends in is the SKE annunciator with the white pitch scale. It would be preferred that the pitch scale overwrite the SKE annunciator with it being masked.

S6. YES: Rating of 2. And some of the symbology on the RANGE side for formation is not very noticeable having the same color symbology as the alphanumerics. Did not notice anything on the right side (Vertical Deviation). Also Command "Chevrons" . Don't stand out to me because of magenta against the background. Yellow would be better. Even command settings at the top. They don't stand out. Rating: 2

S7. Altitude and Airspeed tapes same color as my critical mass bowling ball. Able to easily distinguish symbols from background.

S8. Color makes its pretty easy to track and everything for different information groups. Easy to follow what is associated with what: green - primary; blue- secondary.

S8. Rating: 3: Little white airplane symbol, the word "range" against all other symbols that are white, it is a little jumbled. It could impact performance.

S8. Rating 2: And the same is true on the other side on the diamond, something that would give you a little difference in color so that it would be easier to follow. The altitude one is a little easier to follow because you've got command altitude, in purple or fushia, telling you what altitude you want to be at. So vertical deviation off lead is not as important (as Range). Don't have the same for Range. Just airspeed.

S8. Rating 2 . SKE annunciation when it passes though the white line (i.e., pitch), it doesn't break out real well.

S8. As far as rest of it is pretty easy to clearly see altitude and airspeed.

5. Did you notice any Brightness anomalies (i.e., contrast between symbol and background, roping or variations across the display)? What about overall display brightness?

S1. NO: Very good.

S2. NO: When I first set down, I thought when I fly at night I like it to be dimmer than brighter. First reaction, how could I dim it. Its a little more brighter than I want it.

S4. NO: Really good, very readable.

S6. May be too bright for night flying. Especially when your eyes become acclimated. The dark background is too bright.

S8. YES Rating 2: Steering bar tends to go bright and dark as it moves.

6. Did you notice any image anomalies associated with Flicker, Jitter, and Noise?

S5. YES: Rating of 1. The whites in the pitch lines seem to be flickering.

S5. YES: Rating of 2. SKE bank bar and word seems to be flickering (not on CRT) and yellow and black edges of the bar (same as CRT)

SKE TASKS - SFD SKE Format:

1. Do you have any initial comments regarding the image quality of the display?

S1. It is good.

S2. No, I like it overall.

S3. With sharpness in contrast is easier to read.

S4. Its pretty easy to read. The prox indicator works well.

S5. The clarity is good, very crisp.

S6. Quality is fine.

S8. The dashed line for ownship should be something more meaningful. It doesn't break out real well. The altitude readout on the bottom, too sensitive at 1 foot level, desensitize it to 10 feet increments.

2. Did you notice any Symbol Distortion with any of the display elements? (i.e., stair-stepping, lack of clarity/sharpness, smearing)?

S2. NO: Think its pretty understandable.

3. Did you notice any Symbol Movement anomalies (i.e., ratcheting)?

S4. YES Rating of 2. The movement of 3 seems ratchety and bounces around. Its not a smooth position where lead seems to smoothly track relative to ownship.

S6. YES: Rating of 2. Number 3 guy is jerking around.

S7. Number 3 aircraft moving around rapidly.

S8. Number 3 jerky.

4. Did you notice any image anomalies associated with Symbol Color (i.e., discriminability from other colors and background, color purity, variations across display screen)?

S1. NO: Nothing negative, all good.

S4. NO: Color seems fine.

S5. YES: Rating of 1. Hard to tell the yellow from the white on this background.

S7. NO I can read green lettering better than on CRT.

5. Did you notice any Brightness anomalies (i.e., contrast between symbol and background, roping or variations across the display)? What about overall display brightness?

S2. NO: This isn't so bad. When you have long lines you get roping effect more on the horizontal lines than on the vertical lines.

S8. YES: Rating 2. The caution warning flashing doesn't catch your eye because it wasn't very bright.

6. Did you notice any image anomalies associated with Flicker, Jitter, and Noise?

S3. NO: Same pulsing on #3 aircraft. Probably a simism.

7. Any other display image quality problems? Severity Rating (1-5)

S4. The radar altitude clicking off in feet is annoying and catches your attention. Instead of a straight line for ownship you could have a miniature aircraft symbol. And be able to indicate the direction of lead.

PRECISION FLYING TASKS - PFD:

1. Do you have any initial comments regarding the image quality of the display?

S1. No it's fine.

S2. NO: I really like this CDM. Really helps out for performing the precision flying tasks.

YES: Rating of 2. S2. Lateral steering bar seems to go from dark to yellow.

S3. No, It performed pretty good.

S4. YES: Rating of 2. Bank steering bar has the same little flickering as it moves across the display. Everything else seems to move OK.

S4. YES: Rating of 1. When I descended through 10,000 to 9900 the display showed 09900 for a brief moment.

S5. A little more with the pitch lines with the ripple effect. The CDM is hard to distinguish the center (harder than the CRT).

S5. YES: Rating of 1. I see orange instead of brown. The bowties don't have enough contrast.

S6. Didn't notice anything different than what I commented on. When I was banking, the screen gets lighter when I move my head. Doesn't affect my readability.

S7. Nothing different in image quality.

S8. No real differences (from SKE). Altitude readout good because crossing that. Airspeed readout good because crossing that.

PRECISION FLYING TASKS - SFD MAP Format:

1. Do you have any initial comments regarding the image quality of the display?

S2. Overall, I like it. Neat how detail you can get it. In relation to the old HSI the pointer and tail doesn't seem to be all that big in relation to the heading set marker.

S4. Everything looks good and readable. I like the bearing pointer superimposed over the heading bug. And still have the altitude clicking off in feet which is distracting.

S5. Very crisp and clear.

S6. Quality is fine. Kind of wondering what I do with a heading marker that big. Do you need that precision? Don't understand why you would need a scale that large. Would rather see terrain map or terrain features.

S7. No. Nothing we haven't talked about. I can distinguish waypoints symbols a little better than on CRT. When waypoints fall over route line I can distinguish them better than on CRT.

S8. Altitude sensitivity (bottom digital readout) is still a problem.

2. Did you notice any Symbol Distortion with any of the display elements? (i.e., stair-stepping, lack of clarity/sharpness, smearing)?

S7. NO I can see cross track better.

3. Did you notice any Symbol Movement anomalies (i.e., ratcheting)?

S2. NO: Overall pretty nice.

S3. NO: Normal CRT/LCD screen wavyness, no problem with it.

4. Did you notice any image anomalies associated with Symbol Color (i.e, discriminability from other colors and background, color purity, variations across display screen)?

S1. NO: No complaints.

S6. Only have three colors. The only thing I can't distinguish real easily is the little heading cross. To me that is real important. *(discussion of track cross and heading differences)*

S8. YES. fine. Green numbers at fixed data area on bottom are hard to read, blend into the rest of the display - green range rings.

5. Did you notice any Brightness anomalies (i.e., contrast between symbol and background, roping or variations across the display)? What about overall display brightness?

S1. NO: It's good.

S3. NO: Is good. Just be able to adjust to outside lighting.

S6. Where I am sitting right now too bright. Might be a function of where the screen is located.

S7. YES: Rating 1. Without moving my head, vertical center seems to be brighter than right edge. I don't know why.

S8. Overall display brightness O.K.

6. Did you notice any image anomalies associated with Flicker, Jitter, and Noise?

S8. YES. Rating 1. Runway symbol flickering a little. Route of flight line when oriented straight up and down, there was a flicker, like a raster-like flicker.

PRECISION FLYING TASKS - SFD EXPANDED HSI Format:

1. Do you have any initial comments regarding the image quality of the display?

S2. It's real nice.

S3. No, looks good.

S4. Overall looks good.

S5. I find it clear.

S6. My initial comments are that the CRS arrow, CDI and all that kind of stuff is way too wide, too thick. This is my miniature airplane and I want to line up on the CDI. You may have a tough time finding where the center is to line up miniature airplane. Too wide relative to miniature airplane.

S7. No. Not now.

2. Did you notice any Symbol Distortion with any of the display elements? (i.e., stair-stepping, lack of clarity/sharpness, smearing)?

S1. YES: Rating of 2 A little, all the lines seem to do it has a wave effect on edge.

S4. YES: Rating of 2. Bearing pointer 2 has a roping or wavy effect, it isn't solid and crisp like bearing pointer 1.

S6. YES. Rating of 2. Stair-stepping in the 2 arrow on identifier, tail, and head.

S7. YES: Rating 1. On CDI there is a little snaking, jaggies. When CDI comes across, there is a little wavy motion.

S7. NO. However, not as crisp as it was when I first started. Maybe its my eyes looking at it for so long.

S8. YES. Rating 1. Number 2 in BP2 touching sides.

3. Did you notice any Symbol Movement anomalies (i.e., ratcheting)?

S5. YES: Rating of 1. As it moves the bearing pointer 2 has some noise.

S6. YES. Rating of 2. CDI is jagged, when moving.

S8. NO. Everything seems to be moving across fairly smoothly.

4. Did you notice any image anomalies associated with Symbol Color (i.e., discriminability from other colors and background, color purity, variations across display screen)?

S2. YES: Rating of 2 Noticed blue coloring (BP2) seems to have a floating wave thing to it more than the green.

S5. NO: The green and the blue are distinguishable, better than the CRT.

S6. YES I think the track cross needs to be a different color. Not very distinct.

5. Did you notice any Brightness anomalies (i.e., contrast between symbol and background, roping or variations across the display)? What about overall display brightness?

S6. NO Display is still too bright, though.

S7. YES Rating 1. Center brighter than right edge.

6. Did you notice any image anomalies associated with Flicker, Jitter, and Noise?

S8. YES. Rating 1. A little flicker on BP2 head, not tail, regardless of position.

NAV / APPROACH TASKS - PFD:

1. Do you have any initial comments regarding the image quality of the display?

S2. No, it seemed pretty good it is what I'm use to.

S2. Rating of 2. In the flight director steering bar, dark to yellow with a shadow and seem this to me.

S2. Rating of 2. Bars are flickering. And brown area of ADI not as defined as blue.

S3. No, looks good.

S4. Everything looks good and readable. I like the bearing pointer superimposed over the heading bug. And still have the altitude clicking off in feet which is distracting.

S5. Rating of 1. The #2 bearing pointer does not look like a #2 (worse in the CRT).

S6. Nothing different.

S7. YES. Rating 2 Pitch Steering Bar wavy.

S8. Nothing different. The one thing I don't like is that you don't have any indication of glideslope, other than raw data. So, all of the sudden, it goes wham at glideslope intercept and then it doesn't do you much good.

S8. Pitch Steering Bar a little subdued. Needs to be a little more prominent, maybe a little brighter.

SYMBOL ELEMENT QUESTIONNAIRE RESPONSES

PFD	CRT MEAN	0	0	0	0		LCD MEAN	FREQUENCY				
1. Attitude Direction Indicator (ADI)		5	4	3	2	1		5	4	3	2	1
a) Miniature aircraft symbol	4.75	7	0	1	0	0	4.88	7	1	0	0	0
b) Climb-Dive Marker	4.38	5	2	0	1	0	4.63	6	1	1	0	0
c) Pitch Scale	4.75	7	0	1	0	0	4.75	7	0	1	0	0
d) Bank Pointers / Scales	5.00	8	0	0	0	0	4.75	6	2	0	0	0
e) Bank Steering Bar	4.50	4	4	0	0	0	4.38	5	2	0	1	0
f) Pitch Steering Bar	4.50	5	2	1	0	0	4.50	5	2	1	0	0
g) Glideslope Deviation Indicator	5.00	8	0	0	0	0	5.00	8	0	0	0	0
h) Rising Runway	5.00	8	0	0	0	0	4.75	6	2	0	0	0
i) Speed Worm	5.00	8	0	0	0	0	4.88	7	1	0	0	0
j) Flight Path Angle (dotted line)	5.00	8	0	0	0	0	5.00	8	0	0	0	0
k) MDA / DH Annunciations	4.75	7	0	1	0	0	4.88	7	1	0	0	0
	CRT MEAN	**FREQUENCY**					**LCD MEAN**	**FREQUENCY**				
2. Horizontal Situation Indicator (HSI)		5	4	3	2	1		5	4	3	2	1
a) Aircraft Symbol	5.00	8	0	0	0	0	5.00	8	0	0	0	0
b) Compass Rose	5.00	8	0	0	0	0	5.00	8	0	0	0	0
c) Heading Marker	5.00	8	0	0	0	0	5.00	8	0	0	0	0
d) Track Cross	4.50	5	2	1	0	0	4.25	5	1	1	1	0
e) Course Readout	5.00	8	0	0	0	0	5.00	8	0	0	0	0
f) Bearing Pointer 1	4.88	7	1	0	0	0	5.00	8	0	0	0	0
g) Bearing Pointer 2	4.75	6	2	0	0	0	4.38	4	3	1	0	0
h) Bearing Ptr 1 Identifier / DME	4.63	6	1	1	0	0	4.75	7	0	1	0	0
i) Bearing Ptr 2 Identifier / DME	4.63	6	1	1	0	0	5.00	8	0	0	0	0
j) Course Arrow	4.88	7	1	0	0	0	4.88	7	1	0	0	0
k) Course Deviation Indicator / Scale	4.88	7	1	0	0		4.75	7	0	1	0	0
l) To / From Indicator	5.00	8	0	0	0	0	5.00	8	0	0	0	0
	CRT MEAN	**FREQUENCY**					**LCD MEAN**	**FREQUENCY**				
3. Airspeed Elements		5	4	3	2	1		5	4	3	2	1
a) Airspeed Scale	5.00	8	0	0	0	0	5.00	8	0	0	0	0
b) Digital Readout	5.00	8	0	0	0	0	5.00	8	0	0	0	0
c) Mach Indicator	5.00	8	0	0	0	0	5.00	8	0	0	0	0
d) "Bowtie" Command Marker	4.88	7	1	0	0	0	5.00	8	0	0	0	0
e) Command Digital Airspeed Readout	4.88	7	1	0	0	0	5.00	8	0	0	0	0
	CRT MEAN	**FREQUENCY**					**LCD MEAN**	**FREQUENCY**				
4. Altitude Elements		5	4	3	2	1		5	4	3	2	1
a) Altitude Scale	5.00	8	0	0	0	0	5.00	8	0	0	0	0
b) Digital Readout	4.38	5	2	0	1	0	4.38	5	1	2	0	0
c) "Bowtie" Command Marker	4.88	7	1	0	0	0	4.75	6	2	0	0	0
d) Radar Altimeter Thermometer	5.00	8	0	0	0	0	5.00	8	0	0	0	0
e) Vertical Velocity Indicator	5.00	8	0	0	0	0	5.00	8	0	0	0	0
f) Baro Altimeter Setting	4.88	7	1	0	0	0	4.88	7	1	0	0	0
g) Altitude Alert Readout	4.88	7	1	0	0	0	5.00	8	0	0	0	0
	CRT MEAN	**FREQUENCY**					**LCD MEAN**	**FREQUENCY**				
5. PFD SKE Elements		5	4	3	2	1		5	4	3	2	1
a) SKE Vertical Deviation Indicator	4.63	5	3	0	0	0	4.00	3	3	1	1	0
b) SKE Relative Range Indicator	3.50	1	3	3	1	0	3.75	2	3	2	1	0
c) SKE Lateral Deviation Indicator	4.50	4	4	0	0	0	4.75	6	2	0	0	0
d) SKE Annunciation	4.75	6	2	0	0	0	4.75	6	2	0	0	0

SFD	CRT MEAN	FREQUENCY					LCD MEAN	FREQUENCY				
1. SKE Format Elements		5	4	3	2	1		5	4	3	2	1
a) SKE Ownship	4.25	4	2	2	0	0	4.00	4	2	0	2	0
b) Master Ship	4.75	6	2	0	0	0	5.00	8	0	0	0	0
c) Follower Ships	4.75	7	0	1	0	0	4.50	4	4	0	0	0
d) SKE Route Line	5.00	8	0	0	0	0	5.00	8	0	0	0	0
e) Waypoint Identifier	4.88	7	1	0	0	0	5.00	8	0	0	0	0
f) Proximity Warning Line	5.00	8	0	0	0	0	4.88	7	1	0	0	0
g) SKE Range Rings	4.38	4	3	1	0	0	4.88	7	1	0	0	0
h) ETE / ETA	4.75	6	2	0	0	0	5.00	8	0	0	0	0
i) Status Annunciators (bottom fixed data area)	4.50	4	4	0	0	0	4.63	5	3	0	0	0
j) ZM	not seen						not seen					
	CRT MEAN	**FREQUENCY**					**LCD MEAN**	**FREQUENCY**				
2. Map Format Elements		5	4	3	2	1		5	4	3	2	1
a) Aircraft Symbol	5.00	8	0	0	0	0	5.00	8	0	0	0	0
b) Compass Rose	4.88	7	1	0	0	0	4.88	7	1	0	0	0
c) Heading Marker	4.88	7	1	0	0	0	4.88	7	1	0	0	0
d) Track Cross	4.38	5	2	0	1	0	4.25	5	1	1	1	0
e) Course Readout	5.00	8	0	0	0	0	5.00	8	0	0	0	0
f) Bearing Pointers	4.88	7	1	0	0	0	4.75	6	2	0	0	0
g) Bearing Ptr Identifier / DME	4.75	7	0	1	0	0	5.00	8	0	0	0	0
h) Route Overlay / Waypoints	4.88	7	1	0	0	0	4.88	7	1	0	0	0
i) Range Rings / Labels	4.88	7	1	0	0	0	5.00	8	0	0	0	0
j) Status Annucniations (top fixed data area)	4.25	3	4	1	0	0	4.50	4	4	0	0	0
k) Caution Warning Annunciations (top fixed data area)	4.75	6	2	0	0	0	4.57	6	0	0	1	0
	CRT MEAN	**FREQUENCY**					**LCD MEAN**	**FREQUENCY**				
3. Expanded HSI Elements		5	4	3	2	1		5	4	3	2	1
a) Aircraft Symbol	5.00	8	0	0	0	0	5.00	8	0	0	0	0
b) Compass Rose	5.00	8	0	0	0	0	5.00	8	0	0	0	0
c) Heading Marker	5.00	8	0	0	0	0	5.00	8	0	0	0	0
d) Track Cross	4.63	6	1	1	0	0	4.25	5	1	1	1	0
e) Course Readout	5.00	8	0	0	0	0	5.00	8	0	0	0	0
f) Bearing Pointers	4.63	5	3	0	0	0	4.63	6	1	1	1	0
g) Bearing Ptr Identifier / DME	4.63	6	1	1	0	0	4.50	5	2	1	0	0
h) Course Arrow	4.75	7	0	1	0	0	4.75	7	0	1	0	0
i) Course Deviation Indicator / Scale	4.75	7	0	1	0	0	4.75	7	0	1	0	0
j) Status Annucniations (top fixed data area)	4.38	3	5	0	0	0	4.88	7	1	0	0	0
k) Caution Warning Annunciations (top fixed data area)	5.00	8	0	0	0	0	4.50	6	1	0	1	0
l) To / From Indicator	5.00	8	0	0	0	0	5.00	8	0	0	0	0

SESSION QUESTIONNAIRE RESPONSES

1. Basic Instrument Flight Tasks	CRT MEAN	FREQUENCY					LCD MEAN	FREQUENCY				
		5	4	3	2	1		5	4	3	2	1
a) Determine ground track	4.88	7	1	0	0	0	5.00	8	0	0	0	0
b) Determine pitch	4.88	7	1	0	0	0	4.75	7	0	1	0	0
c) Determine aircraft bank	4.88	7	1	0	0	0	5.00	8	0	0	0	0
d) Determine vertical velocity	5.00	8	0	0	0	0	5.00	8	0	0	0	0
e) Determine heading	5.00	8	0	0	0	0	5.00	8	0	0	0	0
f) Determine airspeed trend info	4.88	7	1	0	0	0	4.75	6	2	0	0	0
g) Determine altitude trend info	4.50	6	1	0	1	0	4.63	8	1	1	0	0
h) Capture / maintain altitude	4.75	7	0	1	0	0	4.88	7	1	0	0	0
i) Capture / maintain airspeed	5.00	8	0	0	0	0	5.00	8	0	0	0	0
j) Capture / maintain heading	4.88	7	1	0	0	0	5.00	8	0	0	0	0
k) Overall basic instrument flight tasks	4.88	7	1	0	0	0	5.00	8	0	0	0	0
2. Navigation Tasks	CRT MEAN	FREQUENCY					LCD MEAN	FREQUENCY				
		5	4	3	2	1		5	4	3	2	1
a) Fly a SID	5.00	8	0	0	0	0	5.00	8	0	0	0	0
b) Navigate using radio-based Navaids	4.88	7	1	0	0	0	4.88	7	1	0	0	0
c) Acquire and maintain course	4.88	7	1	0	0	0	4.88	7	1	0	0	0
d) Fly an ILS Approach	4.63	6	1	1	0	0	4.75	6	2	0	0	0
e) Overall navigation tasks	5.00	8	0	0	0	0	5.00	8	0	0	0	0
3. SKE Tasks	CRT MEAN	FREQUENCY					LCD MEAN	FREQUENCY				
		5	4	3	2	1		5	4	3	2	1
a) Maintain Relative Range	4.25	3	4	1	0	0	4.38	4	3	1	0	0
b) Maintain Vertical Distance	4.50	5	2	1	0	0	5.00	8	0	0	0	0
c) Maintain Lateral Distance	4.88	7	1	0	0	0	4.88	7	1	0	0	0
d) Overall SKE Formation Flying Tasks	4.75	6	2	0	0	0	4.88	7	1	0	0	0
4. Other Tasks	CRT MEAN	FREQUENCY					LCD MEAN	FREQUENCY				
		5	4	3	2	1		5	4	3	2	1
A. Maintain situational awareness	4.88	7	1	0	0	0	5.00	8	0	0	0	0
B. Perform efficient cross-check	4.88	7	1	0	0	0	5.00	8	0	0	0	0
C. Acceptable level of safety	4.88	7	1	0	0	0	5.00	8	0	0	0	0

SESSION QUESTIONNAIRE - COMMENTS

COMMENTS:

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1. BASIC INSTRUMENT FLIGHT TASKS

a) ____ Determine ground track
b) ____ Determine pitch
c) ____ Determine aircraft bank
d) ____ Determine vertical velocity
e) ____ Determine heading
f) ____ Acquire airspeed trend information
g) ____ Acquire altitude trend information
h) ____ Capture/Maintain altitude
i) ____ Capture/Maintain airspeed
j) ____ Capture/Maintain heading
k) ____ Overall basic flight instrument tasks

Subject 1 CRT: g) & h) Looks good function is difficult due to slowing of apparent speed of dial movement when ascent/descent

Subject 2 CRT: c) & j) (Simism)

Subject 4 LCD: g) Switch from 10's to 100's change is altitude is distracting and probably not necessary. Stick with 10's of feet.

Subject 4 CRT: g) Change from 10's to 100's give impression of slowing climb rate.

Subject 5 LCD: f) Trend indicator would be nice/

Subject 5 CRT: f) Acceleration - Deceleration trend indicator would be nice.

Subject 8 LCD: b) distance between 5/10/15 etc is larger than I'm used to and tends to promote over controlling.. f) dial on VVI is easier for me.

Subject 8 CRT: b) pitch ladder too big., promoted over controlling.

2. NAVIGATION / APPROACH TASKS

a) ____ Fly a Standard Instrument Departure (SID)
b) ____ Navigate using radio-based Navaids
c) ____ Acquire and maintain course
d) ____ Fly an ILS approach
e) ____ Overall navigation tasks

Subject 2 LCD: c) & d) Pitch and bank steering bars flicker also seem very thin.

Subject 2 CRT: c) (Simism) (yoke actuator too...)

Subject 3 CRT: a) & b) RRI blends in with ADI

Subject 4 LCD: b) Masking of tail of bearing pointer #2 by heading marker is minor distraction.

Subject 4 CRT: b) Tail of bearing pointing 2 obscured by heading marker.

Subject 6 LCD: d) Bank steering bars are too slow.

Subject 7 LCD: d) Flight Director itself is bad-display is o.k.

Subject 8 CRT: d) Don't want very steer bar to show up at 1/10 dot off; show it sooner.

3. SKE TASKS

a) ____ Maintain Relative Range
b) ____ Maintain Vertical Distance
c) ____ Maintain Lateral Distance
d) ____ Overall SKE Formation Flying Tasks

Subject 4 LCD: a) Not intuitive, but matches current C-141 instrumentation on primary display.

Subject 4 CRT: a) Not intuitive but same as current analog instruments.

Subject 6 LCD: c) Too Sensitive.

Subject 7 LCD:a) Same as CRT- A/C not distinguishable.

Subject 8 LCD: a) Word range is not needed. Takes away from range symbol; symbol needs to be a different color or easier to see.

Subject 8 CRT: a & b) Too much clutter, make symbols easier to see (either color or more space)

4. OTHER TASKS

a) ____ Maintain situational awareness
b) ____ Performing efficient cross-check
c) ____ Can be used with an acceptable level of safety in a standard operational environment

Subject 8 CRT: General comment: CRT sharpness was poor and required extra time to get info.

5. Do you feel that this display configuration can effectively support the following missions?

SOLL 2

Subject 1 LCD:	No experience
Subject 1 CRT:	I have no experience.
Subject 4 LCD:	Unknown, due to NVG compatibility.
Subject 4 CRT:	NVG compatibility
Subject 7 LCD:	However not familiar with mission
Subject 7 CRT:	However not familiar with mission

CAT II Approach
No Responses.

Air Refueling:
No Responses.

Airdrop:
Subject 7 LCD: However not familiar with mission
Subject 7 CRT: However not familiar with mission

Airland:
No Responses

Low Level Tactical:
Subject 6 LCD: Need terrain features displayed.
Subject 6 CRT: Needs terrain and cultural features.

Lengthy Missions:
Subject 2 CRT: Although seems more fatiguing on eyes than LCD.

Other:
No Responses

6. *COMMENTS:*

a) _____ Clutter

b) _____ Character / Symbol Size

c) _____ Off-axis Viewability

d) _____ Display Brightness

e) _____ Color Characteristics

f) _____ Symbol / Background Contrast Characteristics

g) _____ Sharpness / Clarity

h) _____ Overall Useability

Subject 1 CRT: a) (Range) on SKE function a little cluttered- larger aircraft symbol would set it apart.

Subject 2 LCD: d) A little bright (for night fly)

Subject 2 CRT: b) OK., e) though magenta bowtie markers and HDG really jump out more than green etc., g) LCD spoiled me.

Subject 3 CRT: f) MDA and Bowtie could stand out slightly more.

Subject 4 LCD: e & f) Masking of tail of bearing pointer #2 by heading marking. SKE symbol on steering bar mask pitch scale numbers. g) Minor flicker and roping effects.

Subject 4 CRT: g) Slightly out of Focus

Subject 5 LCD: a) SKE mode is a little cluttered. b) Important items should be bigger- DME, etc less important GS, - smaller or deleted.

Subject 5 CRT: a) In SKE Mode "Range" is a little cluttered. b) difficult digits DME, ACT ALERT, etc could be bigger than less important info GS, X-TE. d) in darkened sim. g) I find it a little fuzzy sometimes.

Subject 6 LCD: c) Probably a function of using a notebook computer for the screen. d) Too bright for night missions.

Subject 7 LCD: d) Center and left side seemed brighter than right side of display

Subject 8 LCD: b) DME size bigger, c) Terrible. e) (SKE range/alt pos symbols need a different color)

Subject 8 CRT: General Comments: Sharpness problems due to check characters need to be bigger.

7. Do you think there would be any fatigue effects using this display with prolong use? YES NO

Subject 2 LCD: Depends on what sun glare might effect?

Subject 2 CRT: Would like to see an actual test: Would this be like watching T.V. for 9 hours? If so, self explanatory.

Subject 3 LCD: No excessive effect.

Subject 4 LCD: "Flicker Effects" of some symbols may induce eye fatigue.

Subject 4 CRT: Vision fatigue may be a problem, standard CRT syndrome.

Subject 5 CRT: Fuzziness- I keep trying to focus better not very fuzzy just enough to make me wonder if it's me or the display.

Subject 6 CRT: The fuzzy display would cause fatigue.

Subject 7 LCD: But needs to be tested, have some reservations.

FINAL QUESTIONNAIRE RESPONSES

		FREQUENCY				
	MEAN	Strongly Prefer CRT	Moderately Prefer CRT	No Preference	Moderately Prefer LCD	Strongly Prefer LCD
Q1. Preference for CRT (5) or LCD design (1): Display Components		**1**	**2**	**3**	**4**	**5**
a) ADI	3.63	1	1	0	4	2
b) HSI	3.88	0	1	1	4	2
c) Airspeed indicator	3.25	0	3	1	3	1
d) Altimeter	3.25	0	3	1	3	1
e) SFD SKE format	3.50	0	1	3	3	1
f) SFD Map format	3.50	0	1	3	3	1
g) SFD Expanded HSI Format	3.50	0	1	3	3	1
Q2. Preference for CRT (5) or LCD design (1): Image Quality Parameters						
a) Color Characteristics	3.38	0	2	2	3	1
b) Sharpness / Clarity	4.50	0	0	1	2	5
c) Contrast Characteristics	3.75	0	1	2	3	2
d) Brightness Characteristics	3.25	0	1	5	1	1
e) Image Quality in Dynamic Conditions	3.25	0	2	3	2	1
f) Image Quality in Static Conditions	3.88	0	0	2	5	1
g) Overall Useability	4.00	0	1	0	5	2
Q6. Did you feel that flying position (i.e., right seat, left seat) affected your assessment of the display media?		YES	NO			
	1.88	1	7			

FINAL QUESTIONNAIRE - COMMENTS

1. Please indicate your preference for the following display components.

	COMMENTS
a) ADI	Subject 1: Sharper contrast of many ADI symbols (black outline helps) Subject 2: Sharper image. Subject 4: Sharper image Subject 5: Sharper image less fatigue. Subject 6: Display is crisper Subject 7: Viewing angle problem, cross Subject 8: Visual Clarity
b) HSI	Subject 2: Poss less tough on my eyes? Subject 4: Sharper image Subject 5: Sharper image less fatigue Subject 6: Display is much more crisp. Subject 7: Cockpit flying isn't practical from the co-pilots position. Subject 8: Visual Clarity
c) AIRSPEED INDICATOR	Subject 1: Background color presents a nicer image. Subject 2: Poss less tough on my eyes? Subject 4: Sharper image Subject 5: "Bowtie" markers have better contrast Subject 8: Visual Clarity
d) ALTIMETER	Subject 1: Background color presents a nicer image. Subject 2: Poss less tough on my eyes? Subject 4: Sharper image Subject 5: "Bowtie" markers have better contrast Subject 8: Visual Clarity
e) SFD SKE Format	Subject 2: Poss less tough on my eyes? Subject 4: Sharper image Subject 8: Visual Clarity
f) SFD MAP Format	Subject 2: Poss less tough on my eyes? Subject 4: Sharper image Subject 8: Visual Clarity
g) SFD Expanded HSI Format	Subject 2: Poss less tough on my eyes? Subject 4: Sharper image Subject 8: Visual Clarity

Other Comments:
Subject 3: Overall clarity on LCD was better.
Subject 8: CRT was distorted. I would have strongly preferred LCD except off axis viewing was poor. Also, with bright lights (such as day flying) LCD may not give clarity like CRT.

2. Please indicate your preference for the following image quality parameters.

	COMMENTS
a) Color Characteristics	Subject 1: Airspeed and altitude background better Subject 4: Tail of #2 bearing pointer brighter Subject 7: Viewing angle, can't sit absolutely in the same position the whole mission, changes colors, contrast, ETC.
b) Sharpness / Clarity	Subject 5: It's clearer- cleaner edges. Subject 6: Big improvement Subject 7: Viewing angle, can't sit absolutely in the same position the whole mission, changes colors, contrast, ETC.
c) Contrast Characteristics	Subject 1: LCD ADI easier to see. Subject 5: It's clearer- cleaner edges Subject 7: Viewing angle, can't sit absolutely in the same position the whole mission, changes colors, contrast, ETC Subject 8: LCD was much clearer.
d) Brightness Characteristics	Subject 5: Clearer and easier to look at. Subject 6: Background brightness is not as bright. Subject 7: Viewing angle, can't sit absolutely in the same position the whole mission, changes colors, contrast, ETC
e) Image Quality in Dynamic Conditions	Subject 5: Less distortion (wavy lines during movement) Subject 7: Viewing angle, can't sit absolutely in the same position the whole mission, changes colors, contrast, ETC Subject 8: CRT was better in "moving" situations.
f) Image Quality in Static Conditions	Subject 4: CRT range rings vary in color. Subject 5: Better contrast. Subject 7: Viewing angle, can't sit absolutely in the same position the whole mission, changes colors, contrast, ETC
g) OVERALL USEABILITY	Subject 7: Viewing angle, can't sit absolutely in the same position the whole mission, changes colors, contrast, ETC

3. What characteristics did you **most like** and **least like** about the **CRT?**

Subject 1: Locate PFD and SFD altitude readouts.

Subject 2: Most seems solid state Least: Fuzzier than LCD, impression it would fatigue eyes with time.

Subject 3: Most/All Lettering and numbers were slightly blurred

Subject 4: Least- slightly out of focus. Most- Color slightly brighter, noticeable on narrow lines like tail bearing pointer #2.

Subject 5: Most: Clear symbols during movement - nice colors. Least: Fuzzy around edges of symbols.

Subject 6: Most like background.

Subject 7: I could move my head (blew my nose) and picture was clear and readable.

Subject 8: M- CRT had better clarity in dynamic conditions (no raster or blinking like LCD) L- CRT was fuzzy and not as clear.

4. What characteristics did you **most like** and **least like** about the **LCD**?

Subject 1: Most ADI color and contrast good . Least: SFD altitude too precise

Subject 2: Most: very defined, sharp, easy to read and look at. Least: Side viewing/laptop effect though know this will be N/A

Subject 3: Color contrast on altitude/airspeed CC marker was better sharper images than CRT.

Subject 4: Most: Sharp image. Least: Narrow lines not as bright.

Subject 5: Most: Crisp lines defined edges. Least: "rippling " colors, wavy lines during movement.

Subject 6: Most like crispness. Least liked fuzziness.

Subject 7: Opposite of #3.

Subject 8: M- Very clear picture, good color, clarity etc. L- tended to raster under dynamic conditions.

5. What other characteristics about either the LCD or CRT display do you feel may impact its usability in operational conditions?

Subject 2: Cross Cockpit flying ability might be a problem? Just guessing the glare problems could occur. Seems very useable and a great device under night conditions we used. Can't wait to fly with this equipment!

Subject 4: Failure rate, Background lighting washing out display, eye strain, interference from other electrical equipment.

Subject 5: CRT may be hard to see in bright sunlight.

Subject 6: They're were both too bright for prolonged night operations.

Subject 7: Not sure about bright sunlight and vibration. How about "warm up times"- alert aircraft in the arctic.

Subject 8: Bright sunlit days may distort both (need to ensure viewability under all lighting conditions) use of these displays with NVG's.

6. Did you feel that flying position (i.e., right seat, left seat) affected your assessment of the display media (i.e., CRT / LCD)?

YES NO

If YES, in what way?

Subject 2: a little: right seat display to right of center, had to tilt head to view CRT but really didn't affect opinion on distortion or contrast. Thanks, it was fun!